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The Flight Test Aspects of the Air-Launched Balloon System (ALBS) Development Program

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30 August 1976

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This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

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Chief Scientist

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The Air Launched Balloon System (ALBS) development history is traced and the circumstances leading up to planned ALBS flight tests are described, including a report on successful tests of the cryogenic storage subsystem. The theoretical performance of a candidate parachute development system—35-ft (10.67 m) diameter ring sail drogue, 64-ft (19.51 m) diameter flat circular main chute—is mathematically analyzed using a number of stated assumptions. Contingency arrangements ~~(for example,~~ use of ballast) and their impact are discussed. (e.g.,

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Data ~~presented~~ indicate that the ALBS mid-air deployment concepts require experimental proof-of-concept testing to ensure optimum component selection. Parachute subsystem verification tests planned for the autumn of 1976 at El Centro, California are outlined along with plans for partial and complete ALBS system test drops from a carrier balloon in ~~the spring and summer~~ of 1977 at ~~the~~ White Sands Missile Range.

Preface

The mid-air deployment and inflation of a large balloon system is a challenging technical endeavor. The author has had the pioneering efforts of James C. Payne, his Air Force Geophysical Laboratory colleague, in this area to point the way. Additional guidance has come from related work accomplished by Raven Industries, Inc., for another Air Force effort. In the final analysis, however, the unique parametric values for the very large ALBS system have had to be worked out separately and in great detail in order to achieve confidence in planned test configurations. This report attempts to give some order to the many computations performed by the author and to relate the events that have brought the development program to its present state.

The author owes much to the assistance and encouragement received from his colleagues at AFGL, particularly from Thomas W. Kelly, Director, Aerospace Instrumentation Division, James C. Payne, Francis X. Doherty, James F. Dwyer, and Arthur O. Korn. The advice on parachute testing received from the 6511th Test Squadron at the National Parachute Test Range, El Centro, California has been extremely helpful. Particular thanks go to Clifford W. Marshall and Michael R. Wuest. In the development of the cryogenic gas storage system, the assistance of the Cryogenics Division of the National Bureau of Standards has been invaluable. Sincere thanks are expressed for the dedicated NBS effort so well carried out, with special acknowledgment to Charles F. Sindt and Jess Hord.

The preparation of a manuscript such as this with so many symbols, line illustrations, and tables calls for hard work by many people. Grateful acknowledgment is made to Carol Morth of AFGL and to the personnel of Emmanuel College who participated in the task, with special thanks to Jack Collins, Eileen MacKenzie and M. Patricia Hagan.

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The Flight Test Aspects of the Air-Launched Balloon System (ALBS) Development Program

1. INTRODUCTION

This is the third technical report prepared under AFGL In-House Work Unit (IHWU) 66651101, Air-Launched Balloon Techniques. The first report featured a comprehensive discussion of methods for inflating free balloons in midair subsequent to their deployment from a cargo aircraft or from a high altitude rocket.[1] It concluded that systems employing such methods are capable of being developed and of satisfying a number of identified important military needs.

The second report was more user-oriented.[2] It surveyed all of the various kinds of Lighter-than-Air (LTA) vehicles that might serve as high altitude communications relay platforms, discussing the operational advantages and disadvantages of each, and highlighting some of the technical considerations. It also served as a progress report on the experimental investigations undertaken in connection with the Air Launched Balloon System (ALBS) development program, which was well under way by then and from which a promising LTA communications relay platform was expected to emerge.

(Received for publication 27 August 1976)

1. Carten, Andrew S., Jr. (1973) An Investigation of Techniques for Launching Large Balloon Systems from Aircraft or Rockets in Flight, AFCRL-TR-73-0633.

2. Carten, Andrew S., Jr. (1974) An Investigation of the Applicability of High Altitude Lighter-Than-Air (LTA) Vehicles to the Tactical Communications Relay Problem, AFCRL-TR-74-0399.

This third report will examine the flight test aspects of the ALBS development program in some detail, exploring the dynamics of the mid-air deployment sequence and outlining the proof-of-concept flight tests proposed both to verify those dynamics and to determine system feasibility.

2. BACKGROUND

2.1 Basic Requirement

The Air-Launched Balloon System (ALBS) under development at AFGL is aimed at the requirement for a quick-reaction, lighter-than-air, tactical communications relay platform positioning capability. Such a requirement is called out in TAC ROC 305-75 entitled A Satellite Airborne Communications Relay System for Tactical Air Forces.

Operational planning calls for the packaged ALBS to be extracted from a C-130 aircraft at 25,000 ft (7.62 km). When the system is properly deployed in midair by a tandem parachute array, the stored ALBS balloon will be extended vertically and filled from an attached helium storage unit. The inflated balloon will then carry the communications relay to its assigned altitude [≈70,000 ft (21.34 km)] while the inflation hardware floats to the ground. (See Section 3.3.4 for a more complete operational scenario.)

2.2 Gas Storage Deficiency

In the report entitled An Investigation of Techniques for Launching Large Air Balloon Systems from Aircraft or Rockets in Flight, AFCRL-TR-73-0633, use of the cryogenic gas storage and heat transfer subsystem was proposed for the ALBS.[1] This recommendation arose from the severe weight penalties associated with use of conventional compressed gas storage cylinders, particularly in a system of the size required to put a communications relay on station. The need for a light-weight gas storage medium was identified as crucial, and successful development of the proposed ALBS was seen impossible without a breakthrough in the gas storage area. Subsequent to publication of that report, an agreement was reached between Air Force Cambridge Research Laboratories (AFCRL), the predecessor organization, and the Cryogenics Division of the National Bureau of Standards (NBS), Boulder, Colorado, by which NBS would carry out experimental research in support of the ALBS program. That agreement was most fruitful and led to the design, fabrication, and successful testing of a ground-based prototype cryogenic storage and heat transfer subsystem of the desired capacity. The NBS effort which satisfied the critical ALBS development need is described in a report by Sindt and Parrish.[3]

3. Sindt, C.F., and Parrish, W.R. (1976) A System for Inflating a Balloon Using Helium Stored in the Liquid Phase, AFCRL-TR-76-0012 NBSIR 76-834.

The NBS prototype (Figure 1) uses a hot packed bed aluminum oxide (Al_2O_3) heat exchanger to gasify a predetermined quantity of liquid helium (LHe) and to warm the gas to a suitable temperature for filling the balloon. Its design incorporates all of the functions expected in operational use, where a flight-qualified subsystem of this type would be an integral part of the ALBS package launched from the transporting aircraft. The packed bed is designed to be preheated and put on standby status, awaiting the start of the balloon inflation process. On signal, the dewar is automatically pressurized and helium flows towards the heat exchange unit. Some of the helium passes through the heated bed, and some by-passes it, both streams merging in a mixing chamber. The resultant warmed flow (220 to 260°K average) then passes through the system's inflation tubing into the balloon. Cutoff occurs with depletion of the stored helium. (In an actual air-launch situation, the balloon would be inflated to the proper extent at this point for release and ascent to floating altitude.)

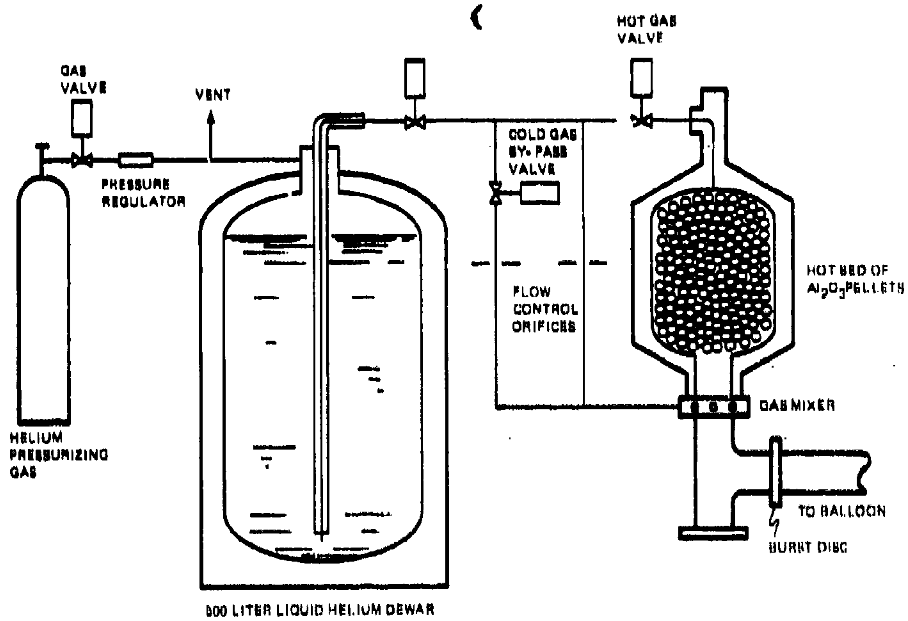

Figure 1. Schematic of the NBS Experimental Cryogenic Gas Storage and Heat Transfer Unit

2.3 Air-Launched Balloon System Subsystem Ground Tests

The prototype ALBS cryogenic storage and heat transfer subsystem was successfully demonstrated in July 1975 at Boulder, by filling a tied down ambient-pressure balloon with 10,590 ft^3 (300 m^3) of helium gas at an average temperature of 260°K in six min and 45 seconds.[4,5]

In November 1975, this same prototype cryogenic unit was transported to Holloman AFB, New Mexico, where it was again successfully employed. There it was used to inflate, on the ground, a 145,000^3 (4106 m^3) balloon which, upon being released, carried a payload of 300 lb (136.08 kg) to 75,000 ft (22.86 km).

The November flight represents the first known flight of a large balloon inflated directly from a cryogenic source.[6] Figure 2 shows the prototype as employed at Holloman AFB. The helium storage medium is the large, cylindrical object towards the front of the truck in the figure and is a heavy 500-liter commercial dewar. The heat transfer unit is the smaller domed cylinder on a stand in the rear of the truck.

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4. The Kelvin temperature scale will be the preferred scale in this report. The reader is asked to remember that 0°C = 273.15°K = 32°F.
   Thus: 260°K = -13.15°C = 8.33°F
   220°K = -53.15°C = -63.67°F.

5. The 220° to 260°K average temperature range reflects system design limits where both physical size constraints for the heat transfer unit and balloon film temperature limitations were carefully considered. With respect to polyethylene film, the allowable temperature extremes were established as 218° and 323°K. Normally, the warmer temperatures are briefly encountered at start-up while colder temperatures are experienced at the end of the run.

6. In the November test approximately 102 lb (46.27 kg) of liquid helium was used for inflation purposes. This is the quantity previously calculated for an operational ALBS in which a 200-lb (90.72 kg) communications relay would be carried to an altitude of 70,000 ft (21.34 km). It should be noted, however, that the 102 lb of LHe actually provides much more than 200 lb of lift. The helium quantity is tailored to the over-all lift requirement, which encompasses not only the weight of the principal payload, that is, the communications relay (200 lb), but also the weights of the balloon, 180 lb (81.65 kg), and of the hardware needed for flight control, 195 lb (88.45 kg), plus 10 percent free lift. (System weights are summarized in Table 1, which appears in Section 3.3.4.)

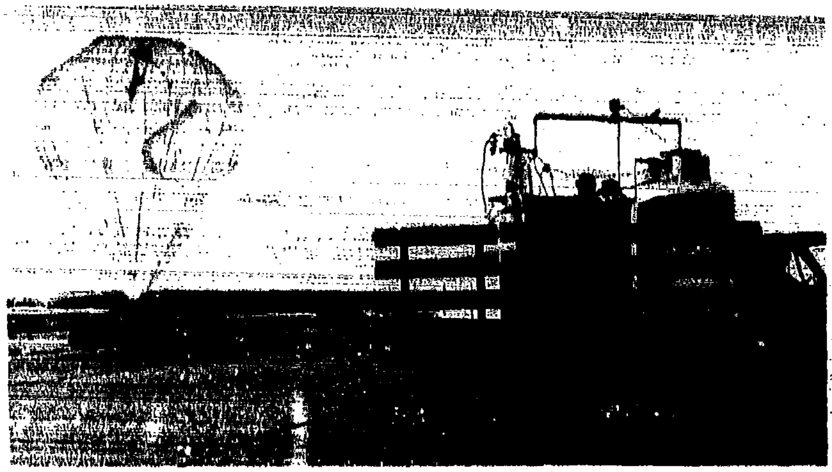


Figure 2. Inflation of Balloon from Liquid Helium Supply

2.4 Flight Test Plans (Preliminary Discussion)

With the basic development tests of the ALBS cryogenic gas storage and heat transfer subsystem thus successfully concluded, the way was opened up for flight tests of the complete ALBS. It was impossible, however, to plan for an aircraft launch of the complete system at the start of the flight test program. For one thing, there was no suitable aircraft - qualified cryogenic unit on hand or in sight. Also, the complicated parachute subsystem required for successful mid-air deployment of the ALBS dictated that this goal be approached methodically. As will be explained shortly, in Section 3, a proof-of-concept flight test program then evolved in which scientific balloons were chosen to serve as the primary test drop platforms. Subsequently, while detailed plans for the balloon tests were being prepared, the opportunity arose to plan for some early drop tests of ALBS partial system mockups from aircraft, to check out the proposed parachute system. This somewhat unexpected turn of events promised to furnish almost immediate answers to uncertainties associated with the deployment subsystem. The opportunity for aircraft drops was seized, therefore, both to advance the cause of the planned balloon tests and to accelerate over-all system development.

As this report is being written, active preparations are under way for the aircraft and balloon drop tests. The aircraft drops are expected to take place at the National Parachute Test Range, El Centro, California during the fall of 1976. Balloon drops of dummy and live ALBS models are planned to be conducted over the White Sands Missile Range, New Mexico, in the spring and summer of 1977. (Please see Addendum for later information.)

2.5 Data Limitations

It would be pleasing to have the test data resulting from the planned drops on hand now for this report. Since this cannot be, the data presented herein are theoretical calculations which indicate how a tentative system design was reached. Only to the extent that the governing assumptions are valid, can the data serve to predict system performance upon release from the carrier vehicle. (Uncertainties which affect the assumptions will be identified at appropriate locations in this report.) This constraint notwithstanding the data presentation does permit a step-by-step examination of the basic functional elements and in many cases, assigns reasonable quantitative values to parameters of interest. Such values are needed for initial sizing of test system components and for allowing test plans to be prepared and implemented with confidence.

It should be noted that the emphasis in this report will be on the balloon flight tests. There will be, of necessity, some discussion of aircraft flight tests also, but the depth of treatment will be less.

3. AIR LAUNCHED BALLOON SYSTEM DESIGN EVOLUTION

3.1 General Considerations

With the previously described ground tests successfully completed, the decision to embark on an ALBS flight test program was inevitable. The main issue was one of scheduling. In other words, how soon after November 1975 could a meaningful flight test—a test which would prove the feasibility of launching LTA relay platforms in midair—be conducted? The answer to this question depended on availability of funds and of special resources, such as a flight-qualified cryogenic unit, a suitable drop platform, and a unique balloon designed for mid-air inflation. It depended also on the ability to work out support agreements with other organizations and personnel (within and outside of AFGL) with respect to balloon design, command-control instrumentation system design, parachute system tests and design verification, launch and recovery operations, and so on. Let us look now at some of these contingency items, to see how they have been handled, and to ascertain the nature of the flight test plan that has evolved.

3.2 Cryogenic Gas Storage and Heat Transfer Subsystem

From the start it was obvious that the cryogenic gas storage and heat transfer subsystem shown in Figures 1 and 2 could not be used in the planned flight tests. The commercial dewar was too heavy and entirely unsuitable for mid-air deployment. (It was used in the 1975 ground-based tests because it was readily available

and because dewar size was not critical in those tests.) The heat transfer unit was also too heavy, though not so much so as the dewar. Thus a new, much lighter and more compact cryogenic gas storage and heat transfer unit now became the critical need.

At first, it appeared that nothing could be done to satisfy this need until the next fiscal year. Then came an unexpected allocation of money from the Laboratory Director's Fund that allowed the experimental work agreement with the NBS to be extended immediately. The design and fabrication of the needed light-weight flyable cryogenic gas storage and heat transfer subsystem were thereupon quickly initiated by the NBS. A scheduled completion date of October 1976 assures that a suitable unit will be available for the flight test program. (See also Section 3.3.2.)

Figure 3 shows the outline of the experimental light-weight cryogenic gas storage and heat transfer unit being constructed by NBS for the flight tests. This new unit has less capacity than the original oversized unit used in the 1975 ground tests, but enough to supply the necessary 102 lb of LHe. (Cf note 6, Section 2.3.) To reduce weight, two titanium liquid hydrogen tanks, left over from the NASA Apollo program and slightly modified, have been employed as the helium dewars. The new configuration also includes a redesign of the original heat transfer unit to lighten it. The estimated gross weight of the new design (dewars + heat transfer unit plus frame and padding) is 653 lb (296.2 kg), about half the weight of the original.

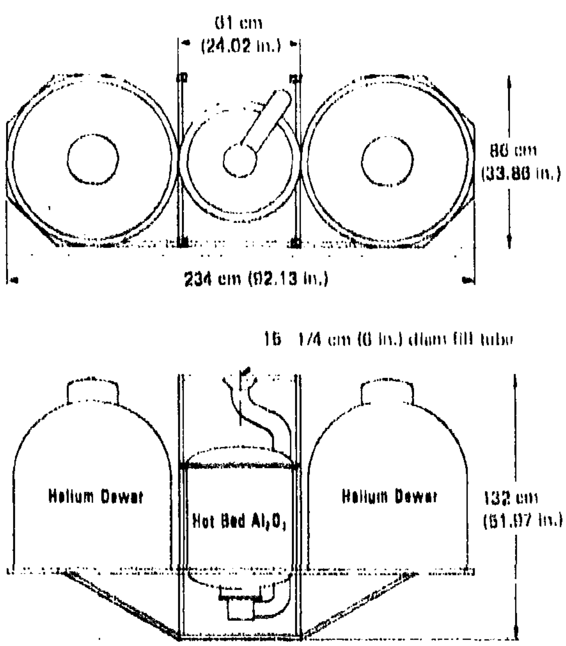


Figure 3. Layout of the Model II Hot Bed and Helium Dewars

3.3 Drop Platform (Aircraft vs Balloon)

Looking at the problem in its simplest terms, that is, the dropping of a package from 25,000 ft (7.62 km) over a test range, one observes that the question of the drop platform becomes that of deciding between an aircraft delivery system and a balloon delivery system, since both vehicles are proven air launch vehicles. The decision made in December 1975 was to employ a balloon as the ALBS drop platform initially. This was a significant decision in that it established the specific direction for the present test program and, at the same time, limited it to a proof-of-concept test. It also effectively added a year to the scheduled initiation date for C-130 drops of the complete system. (Those drops, which will be operational feasibility tests, will be the subject of another report.) The decision to restrict the tests covered by this report to proof-of-concept tests was not taken lightly and it involved several considerations.

3.3.1 FUNDS

To date, the annual allotments of contractual funds for IHWU 66651101 have been devoted almost entirely to the development of the cryogenic gas storage and heat transfer subsystem. Thus, when the go-ahead sign was received in November/December 1975 with regard to flight testing, the author, as unit monitor, instinctively turned to the in-house resources of his parent organization, the Aerospace Instrumentation Division of AFGL, for as much "free" test support as possible. One of the major activities of that division is the conduct of scientific balloon flights, for which it is uniquely well equipped and qualified. The simplest answer to the need for a 25,000 ft drop platform was, if possible, to use one or more of the Division's surplus balloons. With the balloon would come (at some cost) flight instrumentation support, parachute preparation, launch, flight control and recovery support - the complete test package, except for the cryogenic subsystem which would be coming from the NBS. The apparent alternative was to arrange for C-130 drops from an Air Force test activity, which could require the transfer of substantially greater funds than needed for in-house tests. Even if test support funds of the order likely to be required were available, this was not really a viable alternative, however, as will be seen in the next paragraph. Thus, although test support funds (or the scarcity thereof) were involved in the decision making, they were not the overriding consideration in the resolve to use a balloon carrier initially.

3.3.2 AIRBORNE ENGINEERING REQUIREMENTS

To be eligible for C-130 drops, the ALBS cryogenic gas storage and heat transfer subsystem would have to meet the engineering standards established for equipment to be carried aboard aircraft. This was seen as requiring more contractual funds than were immediately available to the work unit and as imposing a severe time penalty. The time delay would result not only from meeting the more stringent design and fabrication requirements of an aircraft-qualified subsystem but also from the need for extensive interorganization coordination.

In view of the fact that a large scale cryogenic mid-air inflation had never been tried before, the author was reluctant to spend (in a stretched-out program) the time and money required for a completely qualified unit, prior to a proof-of-concept demonstration using simpler equipment. His reluctance was greatly influenced by the knowledge that the two surplus titanium dewars were available at the NBS for immediate use in an interim configuration entirely suitable for the proof-of-concept goal, even if airborne engineering standards were not met. Since such a configuration could be put together rapidly and within existing budgetary constraints, it was decided to go ahead with the interim configuration shown in Figure 3, despite the fact that it could not be used in an aircraft drop. By going in this direction the proof-of-concept test could be conducted much sooner. Naturally, this decision mandated the use of a balloon launch platform in the proof-of-concept test. (The ultimate version of the cryogenic unit, which will be dropped from C-130 aircraft after proof-of-concept is established, has yet to be designated in detail. It must be more compact, of course, in keeping with aircraft cargo density requirements, and will feature a single dewar, probably made of aluminum whose capacity equals that of the two titanium dewars combined.)

3.3.3 FLEXIBILITY

A third factor which influenced the balloon choice was the matter of test bed flexibility. Balloon systems are very flexible with regard to system configurations, being particularly amenable to last minute changes, add-on components, and the like. In addition, they are insensitive to the drag considerations associated with high-speed aircraft deployment and they offer a relatively gentle launch environment. These qualities are important to an experimenter at the proof-of-concept stage. In the event of a system modification, for example, to overcome a deficiency noted in the initial drop test, the flexibility afforded by balloon systems would permit a much faster turn-around time than is liable to be the case when airborne engineering requirements must be met.

3.3.4 RELEVANCE

The ALBS flight test program, to be a valid endeavor, must relate strongly to the anticipated operational usage of the system. Before assessing the validity of test configurations involving the use of balloon carriers, we consider it appropriate at this point to review the envisioned ALBS operational scenario in greater detail:

Proposed ALBS Operational Scenario

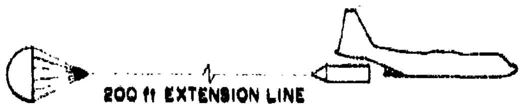
The operational ALBS module to be extracted from the C-130 aircraft is expected to weigh approximately 1430 lbs (648.65 kg) and will be approximately 3 ft x 3 ft x 12 ft (.91 x .91 x 3.66 m). (These dimensions are for a unit designed to put a 200-lb (90.72 kg) communication relay on station at 70,000 ft (21.34 km). See Table 1 for a breakdown (estimated values) of the over-all system weight. See Figures 4a and 4b for a depiction of the extruction process and first stage deceleration). Integrally mounted runners are planned to aid the extraction process. No palletizing is envisioned.

Table 1. Air-Launched Balloon System Weight Breakdown (Estimated Values)

Item	lb	kg
Drogue chute (35 ft (10.67 m) ring sail	23	10.433
Extension line [200 ft (60.96 m)]	9	4.082
Shackles, triplate	10	4.536
EV-13 valve, strobe light	10	4.536
Balloon, ALBS, reefed	180	81.648
Subtotal	232	105.235
Main chute (64 ft (19.51 m) flat circular)	100	45.36
Item	**lb**	**kg**
Main canopy apex frame	50	22.68
Comm. relay	200	90.72
Command/control	40	18.144
Recovery chute	20	9.072
Ballast, etc.	125	56.70
Filling tube, clamps	10	4.536
Cryogenic unit	653	296.200
Subtotal	1098	498.053

Total System Weight

lb	kg
232	105.235
100	45.36
1098	498.053
1430	648.648



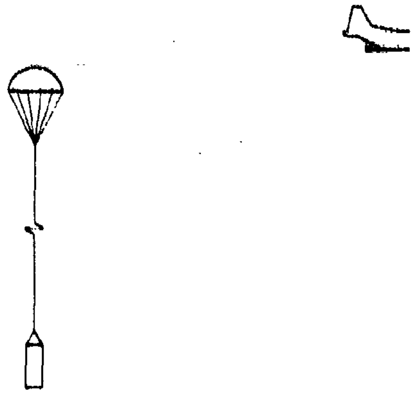


Figure 4. Extraction of ALBS Module from C-130

The module, which will be oriented vertically after extraction, will consist of several compartments, one above the other. (These compartments are shown later in Figure 7b.) The topmost compartment will contain a packed 157,000 ft^3 (4446 m^3) ALBS balloon. Below this will be the communications relay and command-control instrumentation. The next lower compartment will contain a packed 64 ft (19.51 m) flat circular main canopy. The top surface of the canopy compartment will be permanently secured to the main canopy in the vent area and will serve as the base for the compartments above. Below the main canopy compartment will be the compartment for the cryogenic helium storage unit.

A 35 ft (10.67 m) ring sail parachute has been tentatively selected (see Section 4.4.1) for achieving extraction and first stage deceleration. A 200 ft (60.96 m) line will separate this chute, referred to as the "drogue chute" from the ALBS module and will be fully extended at the time of extraction. When the system descending on the drogue chute has reached equilibrium velocity, the cryogenic unit will be commanded to separate from the rest of the module, free falling and dragging down the main canopy lines with it, including a center vent pull line. (Figures 7 to 13, which appear later in this report, should be consulted here for a clearer understanding of these events.) When the main chute inflates, and the array has reached a new equilibrium velocity, the drogue will be disconnected from everything but the apex

of the balloon stored on top of the main canopy. The unloaded drogue will then slow down, while the main chute accelerates. The velocity differential is expected to pull the balloon out vertically until there is tension between the two chutes again and another equilibrium velocity is achieved. Inflation of the balloon will be initiated at that point and will require about 5 min. The drogue will be cut away about halfway through the inflation. When inflation is complete, the ALBS balloon will pull away from the main canopy, carrying the communication relay payload to float altitude. The inflation hardware will descend on the main canopy.

The entire sequence is expected to take approximately 6 min, during which time the system will have descended from 25,000 ft (7.62 km) to approximately 16,000 ft (4.877 km).

When the foregoing scenario is analyzed, many discrete sequential "events" can be identified. A reliable criterion of the validity of a balloon drop test is the number of such events and time sequences common to both types of deployment, that is, aircraft drops and balloon drops. Clearly, the higher the number the more valid the test.

Table 2, (Section 4) lists and assigns identifying numbers to the events and times for a balloon release. The listing includes not only the actual drop from the balloon but also all subsequent events until the completely-inflated ALBS balloon pulls away from the main canopy and starts to ascend. Except for minor differences in completion times, a similar listing of events for an aircraft release would be identical, after designated event 2b, when the drogue has reached equilibrium velocity. (See note 7.) Since the completion of event 2b occurs within the first 16 sec of a 360-sec process and since all events subsequent to event 2b are identical, regardless of the drop method, it would appear that, in keeping with the criterion presented above, a balloon drop test is, indeed, a valid system test.

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7. Balloon drop steps 2b, and earlier, differ from early aircraft drop steps because, in the initial phase of the aircraft drop, the drogue is at least partially inflated before the module is released from the carrier (Figure 4a). In the balloon drop initial steps on the other hand, there is a free-fall period of about four sec while the extension line is deployed. This occurs before the drogue begins to open. Moreover, system attitude is vertical at all times in a balloon drop, whereas a translation of the falling system from horizontal to vertical attitude must be accomplished in an aircraft drop (Figure 4b).

3.4 The ALBS Special Balloon

Mentioned earlier as a prerequisite flight test item was the special ALBS balloon designed for mid-air inflation. This is the balloon which will be compactly stored in the ALBS module in an uninflated state. The initial design of this balloon has been established and three balloons are currently being built by Winzen Research, Inc., to that design. Availability for test purposes seems assured, therefore.

As with the parachute deployment process (Section 3.5) there are uncertainties connected with the mid-air inflation of the special ALBS balloon. These are related to assumptions employed with regard to the helium transfer rates, the balloon "bubble" drag coefficient, the lift to mass ratio, and so forth. (See Section 4.4.6.) The dynamic behavior of the balloon itself while the inflation process is going on is also very important and not completely predictable at this time. There is some fear, for example, that the balloon may twist during inflation, pinching off its gas supply tube and causing it to burst, thus aborting the mission. Also, no consideration has been given to possibly adverse horizontal wind effects.

It would be desirable to resolve as many of these uncertainties as possible with dummy tests, to avoid risking the expensive flyable cryogenic unit. The El Centro tests (Sections 3.5 and 3.6) will effectively do this with respect to decelerator performance during the balloon extraction process and, in addition, will test the survivability of the proposed gas transfer hose, made of 3-mil (.0076 cm) thick, 9.64-in. (24.5 cm) wide layflat polyethylene tubing. (This hose will be attached to the center vent pull line, Section 4.4.4.) The initial balloon drop test(s) (Section 3.6) will complement the El Centro demonstrations and resolve other uncertainties such as those associated with drops of heavy loads from carrier balloons. The actual mid-air inflation of the special ALBS balloon cannot be simulated, however, and demonstrating the feasibility of that process will be one of the major goals of the "live" primary test of June-July 1977. The preceding dummy-oriented tests will, it is hoped, contribute substantially to a smooth proof-of-concept test demonstration at that time.

As a matter of interest, the fully inflated ALBS balloon will be considerably smaller than the carrier balloon from which the module will be dropped (a volume of 157,000 ft^3 (4446 m^3) for the ALBS balloon vs one of approximately 800,000 ft^3, (22656 m^3) for the initially-selected carrier balloon). (See Section 4.4.2, note 11a.) The ALBS balloon will have two novel features which are being added to meet the special mid-air inflation requirement: an internal inflation tube, running along a gore from base to apex, and a special base end fitting which both supports the

ALBS payload and accommodates the inflation tube. This balloon will also be reefed, to protect the slack material from buffeting during the mid-air inflation process. Specifications for the special ALBS balloon are given in Appendix B.

3.5 The Parachute Subsystem

In Section 2.4, mention was made of the "complicated parachute subsystem required for successful mid-air deployment of the ALBS." It should be stressed that this subsystem is configured around standard parachutes and that no parachute development is envisioned. The complications arise from the intended use of those parachutes. To appreciate the nature of the complication, it is necessary now to examine the mid-air deployment problem in greater depth. (See Section 4.)

As we conduct this examination it will become obvious that there are many questions yet to be resolved. Nevertheless, there appears to be no compelling reason why the planned tandem parachute system will not do the assigned job. The many calculations carried out to reach the values entered on Table 2 and discussions of the system with experienced parachute test personnel have generated enough confidence in the planned array to proceed to ALBS parachute system flight testing at El Centro using dummy payloads. It is to be expected, of course, that those tests will introduce refinements to the general concept, which, in the long run will aid over-all system development.

3.6 The Primary Test Plan

With the hopeful assumption that balloon drop test validity has been clearly established (Section 3.3.4), and with the demonstrated availability of the critical test components (Sections 3.2, 3.4, and 3.5), the discussion will now continue on the basis that the primary test plan will be to drop a complete ALBS module (including the cryogenic unit of Figure 3) from a carrier balloon. The tentative operational details of the plan are as summarized on Table 2 and covered in depth in Section 4. The scheduled time period for carrying out the planned balloon drop of the complete ALBS module is June-July 1977. The parachute system tests to be conducted earlier from C-130 aircraft at El Centro (November 1976-January 1977) and the planned dummy system drops from a carrier balloon at Holloman AFB (March-April 1977) are, in effect, dress rehearsals and subsystem shakedown tests prior to execution of the primary test. Because they will be based on the events planned for the primary test, they will not be described in any detail in this report.

4. THE MID-AIR DEPLOYMENT PROBLEM

4.1 General Considerations

The mid-air deployment problem simply stated is one of bringing about the controlled descent of the ALBS module after it has been launched from the carrier aircraft (or balloon), while, at the same time, using elements of the deceleration system to extract the folded ALBS balloon from its container and to stretch it out for inflation.

If controlled descent were the only requirement, there would be no problem. Standard air cargo extraction and deceleration systems would meet the stated needs very nicely and would require only routine operational preparations. The problem arises from the second functional element, the need to deploy the balloon vertically (and gently) to its full length—102 ft (31.0 m)—while the entire array is descending.

4.2 Parachute Arrays

It is clear from previous discussions of the ALBS operational scenario (Section 3.3.4) that at least two parachutes are needed for mid-air deployment of the ALBS system: a smaller upper parachute, called the "drogue chute," and the lower and larger main parachute or "main canopy."[8]

4.2.1 EARLY ALBS PARACHUTE CONCEPTS

Figure 5 shows the parachute array originally proposed for the ALBS application.[1] As can be seen from the figure, that array is designed for deployment of the ALBS balloon below the main canopy. In this report the above-the-main canopy deployment method will be the preferred method and the array to be described is more suited to that method. This preference is based on later engineering discussions at AFGL in which it was concluded that the below-the-main canopy method subjects the balloon to excessive strain and introduces the probability of main chute collapse as the balloon begins to fill. It also causes an increase in system weight by requiring an extra recovery parachute, since the main chute cannot be used for that purpose. Below-the-main canopy deployment will not be further discussed and Figure 5 will be regarded as an obsolete concept.

8. A possible third parachute is a separate "extraction chute" to pull the module out of the aircraft. It is probable, however, that the drogue chute (possibly reefed) will serve also as the extraction chute in any operational ALBS system. For that reason the ALBS flight tests are configured around a two-parachute system. Figure 5 shows a separate extraction chute, as well as the drogue and main chutes. The depicted configuration is for reference purposes and does not represent current planning.

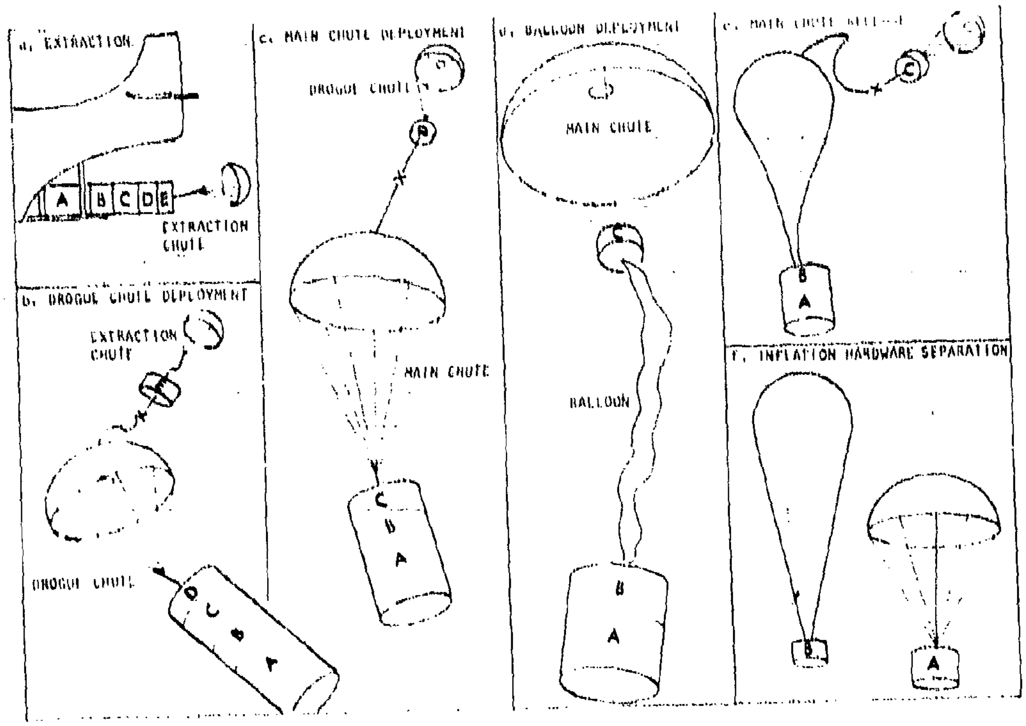

Figure 5. Originally Proposed ALBS Deployment Sequence (Now obsolete)

4.2.2 CURRENT CONCEPTS

Figures 6 through 13, which appear later in this report, describe the various stages in the deployment of the parachute array now planned for use in the ALBS test program. Although a carrier balloon appears in Figure 6, at the start of this sequence of illustrations (page 28) the arrangement shown, minus the safety chute and balloon load bar, is basically similar to the arrangement which would be used in a launch from an aircraft. For example, the system illustrated in Figure 7a, (page 31) Drogue Chute Deployment, could be either (a) one dropped from a balloon or (b) one extracted from an aircraft and shown after the horizontal component of motion had disappeared. In either case, the main canopy would be packed at this point and the drogue alone would accomplish the initial deceleration task (first stage deceleration).

Parachute clusters are fairly common, particularly in the dropping of very heavy cargoes. Vertically-separated tandem arrays, such as the one proposed here, are less common but are used in specific applications such as in the recovery of drone aircraft. The top loading of the main canopy and the alternate unloading and loading of the drogue chute during the main canopy deployment and the ALBS balloon extraction process (Figures 8 to 10) represent a marked departure from standard parachute techniques, however, and introduce uncertainties that can be resolved only by actual experiment. Thus, the tests to be conducted at El Centro assume critical importance in this report.

4.3 Drop Altitude

Both the parachute system tests to be made from a C-130 aircraft and the drops to be made from a carrier balloon will utilize a 25,000 ft (7.62 km) release altitude.[9] This altitude has been selected because it corresponds to the maximum allowable extraction altitude of C-130 operations, a factor which is governed by Air Force regulations with respect to crew safety. Thus, the 25,000 ft altitude position becomes the key point of reference in the drop sequence.

4.4 Sequence of Events

4.4.1 GENERAL

In both types of launch (balloon and aircraft) several specific "events" will follow the release command (Section 3.3.4). The events associated with the release of the live ALBS module from a carrier balloon are identified in Table 2, along with the estimated altitudes and times at the completion of each event (Figures 6 through 13 depict the major events in this sequence.) Comparable aircraft drop events are not separately listed here but, as explained in Section 3.3.4, are identical to those specified for the balloon drops in Table 2, once event 2b has been completed.

Per the data limitations of Section 2.5, the time, altitude and velocity values shown in Table 2 for the balloon drops are, at best, approximations. They were obtained by selecting specific parachute sizes and types (in this case, for example,

9. From a general operational point of view the 25,000-ft drop altitude is considered highly desirable in that it reduces the time required to put the relay on station (the balloon has a shorter distance to climb), and also allows vertical maneuvering space over mountainous terrain. Specific operational considerations may dictate the use of a somewhat lower altitude, however.

Table 2. Sequence of Events, ALBS Mid-Air Deployment

(Carrier Balloon Used as Drop Vehicle)

EVENT NUMBER & DESCRIPTION	EVENT TIME (Sec)	CUMULATIVE TIME (Sec)	EVENT COMPLETION ALTITUDE (FT)	(M)	EVENT COMPLETION VELOCITY (FPS)	(MPS)
1. Free Fall Phase						
a. Special shackle releases 4 suspension straps. ALBS components start to free fall (Drogue packed; main chute packed, ALBS module weight = 1430 lb (648.65 kg)	0.5	0.5	25000.	7620	0	0
b. 200' (61m) [illegible] the pack out, [illegible] taut; pulls [illegible] line of drogue chute.	4.0	4.5	(D) 25000 (S) 24800	7620 7559	(D) 0 (S) -113	-34.44
c. Drogue chute is pulled out of pack, becomes taut.	1.0	5.5	(D) 24874 (S) 24674	7582 7521	-145 (both)	-44.20
2. Drogue Inflation						
a. Drogue chute inflates. (Opening Shock =2g)	3.5	9.0	(D) 24487 (S) 24287	7464 7404	-73.80 (both)	-22.52
b. Drogue chute reaches equilibrium velocity.	6.3	15.3	(D) 24072 (S) 23872	7337 7276	-58.87 (both)	-17.94
3. Main Chute Deployment						
a. Main chute is deployed. (Shock = 5.1g)	2.2	17.5	(D) 23971 (S) 23771	7306 7245	-47.62 (both)	-14.51
b. Main chute is opened (Shock = 2g)	3.5	21.0	(D) 23828 (S) 23628	7263 7202	-30.32 (both)	9.24
c. Both chutes at equilibrium velocity. (Loads: Drogue 339 lb, Main 1091 lb, or 154 kg, and 495 kg).	1.8	23.8	(D) 23747 (S) 23547	7238 7177	-28.52 (both)	8.69
4. Balloon Extraction						
a. Special shackle releases 2nd set of suspension lines 70% of drogue load is transferred to main chute.	0.5	24.3	(D) 23722 (S) 23522	7230 7170	-28.37 (both)	-8.65
b. Dual chutes uncouple, pull apart (dragging ALBS balloon out of container on top of main chute.)	9	33.3	(D) 23403 (S) 23248	7130 7086	-23.21 -29.60	7.07 9.05
c. System achieves a new equilibrium velocity.	3.0	36.3	(D) 23406 (S) 23161	7134 7059	-28.20 (both)	8.60
5. Balloon Inflation						
Inflation of balloon.	200.5	[illegible]	balloon 16,000	4877	-20	6.10

(D) refers to drogue chute (35 ft (10.67 m) ring sail)
(S) refers to components mounted on top of main canopy (64 ft (19.51 m) flat circular) normally 200 ft. below drogue.

a 35-ft diameter (10.67 m) ring sail drogue and a 64-ft (19.51 m) flat circular main canopy) and by employing standard equations for determining acceleration, deceleration, drag, equilibrium velocities, and so on. In almost every case some starting or governing assumption had to be made. The various sections of this report and its appendices discuss the calculations and assumptions employed to reach the values entered on Table 2. In the end, the true values for the events listed will be known only after the completion of the experimental program. In the meantime, the values are considered adequate for guidance in planning flight instrumentation and command-control equipment for the test program. They also show that the inflation sequence will be completed at an altitude which provides both a safe clearance above the test range terrain and a margin of safety (height wise) to accommodate some error in calculated event completion times.

It should be mentioned here that the choice of a 35-ft (10.67 m) ring sail drogue was based on theoretical considerations and does not reflect the actual availability of this parachute. Other possible contenders are a 43-ft (13.11 m) ring sail chute, a 40-ft (12.19 m) ring slot (heavy) chute and a light-weight 32-ft (9.75 m) ring slot chute. If a drogue chute other than a 35-ft ring sail is used the velocity and altitude values shown in Table 2 will no longer apply, except as rough approximations, and a new Table 2 will have to be constructed, using the same methods of calculation.

4.4.2 BALLOON DROP, EVENT NO. 1, FREE FALL PHASE

As shown in Table 2, the first balloon-drop event has three parts and will begin when the "release" or "drop" command is given to the carrier balloon (Figure 6).

At that command a pyrotechnic "squib" will be fired, causing the load bar of a special shackle (Tenney release) to pivot downward (see detail, Figure 6). Thereupon, the four suspension straps with steel ring end fittings, which, in conjunction with the Tenney release, connect the 1430 lb (648.65 kg) ALBS module[10] to the carrier balloon, will slide off the Tenney load bar. This release action, which initiates the free-fall descent of the module, has been designated event 1a and is expected to take only 0.5 sec. No altitude change is involved.

10. The 1430 lb (648.65 kg) module weight figure is based on the figure stated in the proposed operational scenario (Section 3.3.4). It includes the weight not only of the system which is eventually to rise to float altitude but also of the additional components necessary for mid-air deployment and inflation. The latter items will parachute to earth when the inflation operation is completed. (Refer back to Table 1 for a system weight breakdown.)

Caution: No provision has been made in Table 1 for possible parachute ballast weights. During the El Centro tests, various ballast combinations will be tried, to determine how much ballast is needed, if any, to assure positive and rapid inflation of the 64-ft main chute and to compensate for the effects of apex loading. If such ballasting proves necessary, the 1430 lb module weight will have to be revised upward (see also Section 4.4.4), and the data of Table 2 will have to be recalculated.

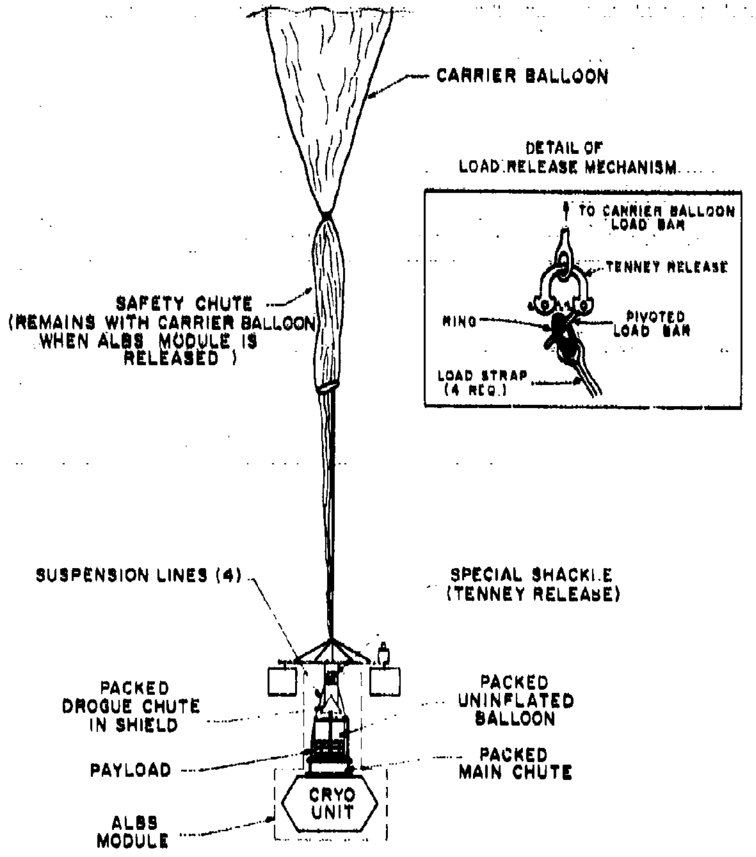

Figure 6. ALBS Flight Test System at Float Altitude (25,000 ft)

The packed drogue chute remains attached to the carrier balloon during the succeeding four sec, which is the free-fall duration required for deployment of the 200 ft (60.96 m) extension line. (During the fall, one end of the line is attached to the ALBS module, the other to the packed drogue.[11]) This action constitutes event 1b. The purpose of the extension line, incidentally, is to provide sufficient vertical clearance between the two parachutes later on so that the wake from the main chute will not adversely affect the performance of the drogue.

When the extension line slack is used up (at the end of event 1b) the drogue chute will be pulled out of its pack located in a shield attached to the carrier balloon and its lines will become taut in about 1 sec, ending the ALBS free-fall phase. This is event 1c. Total elapsed time is 5.5 sec at this point. The module has fallen approximately 326 ft (99.36 m) and has reached a downward velocity of 145 ft/sec (44.20 m/sec). Table 3 shows the velocities and height differentials with time associated with this free-fall period. (Rounded-off Table 3 velocity and $\Sigma \Delta H$ values for 3.5 and 4.5 sec have been used in Table 2 for events 1b and 1c even though the cumulative completion times for those events are 4.5 and 5.5 sec, respectively. The 1-sec difference is accounted for by the non-fall 0.5-sec time of event 1a and by a built-in 0.5-sec lag to compensate for expected friction effects.)

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11. The 4-sec free fall is based on the assumption that the carrier balloon will hover momentarily at the release altitude, after the separation of the module occurs, at least long enough to permit the extension line to pay out and become taut. If the balloon rises (see note 11a) during this short period, it will accelerate the deployment of the extension line and decrease both the free fall period and the downward velocity of the module at the time of drogue chute opening. The effect on the equilibrium velocity of the drogue at the end of event 2b will be slight, however.

11a. The actual behavior of the carrier balloon at the moment of module release will depend on a number of factors whose magnitude cannot be forecast accurately at this stage of planning. An obvious effect to be expected is an upward movement associated with the relaxation of the balloon material and with the gain in buoyancy. This can be offset somewhat by releasing (valving) some of the carrier's lifting gas and by preloading the carrier with extra ballast to reduce the percentage of the carrier's gross load lost at ALBS release. However, since a heavily-ballasted carrier balloon must be made of high-strength material, and since such balloons are quite expensive and are not well represented in the balloon inventory, extra ballasting may be infeasible. The gross weight which the carrier balloon must lift will not be known until after the El Centro parachute system tests where parachute ballast requirements are also being established. Only then will it be possible to ascertain true gross system weights and permissible ballast provisions.

Table 3. Free Fall Chart

Time (t) Sec	Δt	Alt. (H) (ft)	v (fps)	$\bar{V}$ (fps)	ΔH(ft)	$\Sigma\Delta H$ (ft)
0	0	25,000	0	0	0	0
1	1	24,983.9	-32.2	-16.1	-16.1	-16.1
2	1	24,935.6	-64.4	-48.3	-48.3	-64.4
3	1	24,855.1	-96.6	-80.5	-80.5	-144.9
3.5	.5	24,802.8	-112.7	-104.65	-52.32	-197.2
4.0	.5	24,742.4	-128.8	-120.75	-60.38	-257.6
4.5	.5	24,674.0	-144.9	-136.85	-68.42	-326.0
5.0	.5	24,597.5	-161.0	-152.95	-76.48	-402.5

Free Fall Formulas:

$$\Delta H_1 = \frac{v_0 + v_1}{2} \times \Delta t = \bar{V} \times \Delta t$$

$$= 0 + \frac{(-32.2)}{2} \times 1 = -16.1$$

$$\Delta v = -32.2 \text{ fps } (-g) \text{ for } \Delta t = 1 \text{ sec}$$

$$= \frac{-g}{2} \text{ for } \Delta t = 1/2 \text{ sec}$$

$$v_1 = v_0 + \Delta v$$

$$= 0 + (-32.2)$$

$$= -32.2 \text{ fps}$$

$$v_2 = v_1 + \Delta v$$

$$= (-32.2) + (-32.2)$$

$$= -64.4 \text{ etc.}$$

4.4.3 BALLOON - DROP EVENT NO. 2, DROGUE CHUTE INFLATION

It has been assumed that the extracted 35 ft (10.67 m) diam ring sail drogue chute[12] will begin to inflate as soon as its lines become taut. It has also been assumed that the effective area of the drogue chute will increase linearly with time during the opening. These assumptions are in accord with standard parachuting

12. In an aircraft launch, the 200-ft extension line is expected to be fully deployed by the extraction chute before the module is pulled from the rear of the C-130 transport (Figure 4a). The module will then swing down through a 200-ft arc, and after some oscillations, will begin a vertical descent (Figure 4b). In this case, the equilibrium velocity of the drogue chute will be slightly different from that shown for a balloon drop. The same holds true for the event 2b completion altitude. These discrepancies will carry through the other events, but are not significant enough to warrant a separate table for aircraft-drop events.

practices. An opening time of 3.5 sec has been allowed for the drogue, using the method described in the <u>Parachute Handbook</u>[13] for parachutes with geometric porosity. (See note on computation sheet for events 2a and 2b, Appendix A, Table A1.) Table 2 shows that the drogue chute has decelerated from -145 fps (-44.20 mps) to -73.89 fps (-22.52 mps) at full opening and reaches an equilibrium velocity of -58.87 fps (-17.94 mps) 6.3 sec later, at the end of event 2b (cf. Figure 7a). At this point the drogue is at 24,072 ft (7.337 km), 200 ft (60.96 m) above the module. The opening shock is 2.15 G, well within the design capability of the ALBS module. (See Appendix A for back-up computations.) The schedule now calls for deployment of the main canopy.

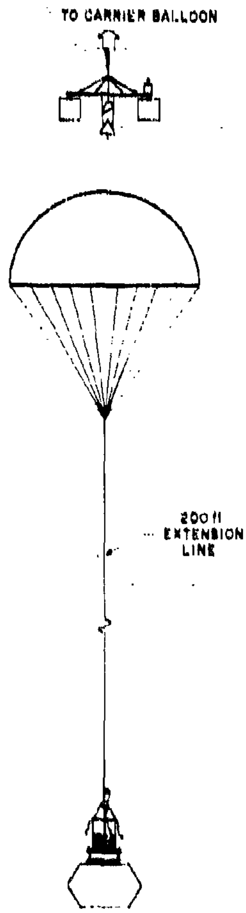

Figure 7a. ALBS Flight Test: Drogue Chute Deployment (First Stage Deceleration)

13. Performance of and Design Criteria for Deployable Aerodynamic Decelerators, ASD-TR-61-579, 2nd Ed., Dec. 1963.

4.4.4 BALLOON DROP EVENT NO. 3, MAIN CANOPY DEPLOYMENT AND INFLATION

Up until this point the 64-ft (19.51 m) flat circular main canopy has been packed in a special compartment above the cryogenic unit in the descending ALBS module. Figure 7b is a preliminary cutaway view of the compartmented module.[14]

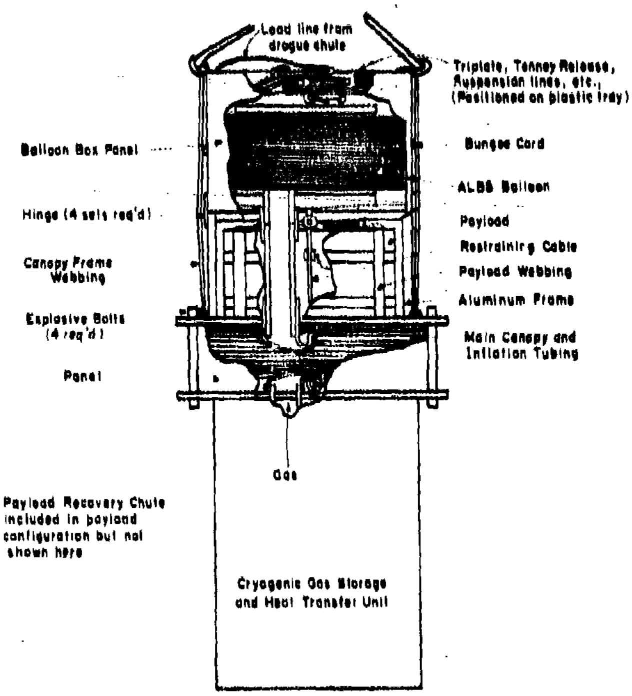

Figure 7b. ALBS Module

14. The discussion which follows assumes that the design shown in Figure 7b will be used. It is very likely, however, that the El Centro tests will lead to a somewhat different configuration. A special point of concern here is the interface between canopy material (nylon) and possibly sharp edges on the canopy frame. The design shown in Figure 7b does not adequately treat this problem area.

A timer-activated signal will now fire the explosive bolts (or equivalent devices) which have held the parachute compartment together. The heavy cryogenic unit will immediately fall away pulling down the lines of the 64-ft chute with it. The top of this chute remains secured to the upper plate of the parachute storage compartment (cf Figure 8).

The estimated event completion time for deployment of the main canopy is 2.2 sec (event 3a). This is the time[15] it takes the free-falling cryogenic unit to move approximately 68 ft (20.73 m) away from the drogue-supported components, which are falling (descending) at a slower rate. The 68-ft distance is the length of a center vent pull line which, in effect, brings the cryogenic unit up short before the main canopy's suspension lines become taut. This device is considered necessary to ensure the subsequent opening of the main canopy. Otherwise, with tension on the top (from the drogue) and on the bottom (from the cryogenic unit) there might not be enough air entering that chute at the indicated end-of-deployment velocity (-47.62 fps, -14.51 mps) to open it. See Table 4 for a synopsis of the main canopy deployment calculations, in English units.

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15. The actual time required for the 68-ft (20.73m) separation is 1.70 sec(Table 4). The stated deployment time of 2.2 sec includes an arbitrary 0.5-sec time period for line stretch and shock absorption before the main chute starts to open. During this time period the free-falling mass (cryogenic unit, main canopy, filling tube) decelerates from the velocity at the end of free fall (-113.64 fps, -34.64 mps) to that of the drogue at 2.20 sec (-47.62 fps, -14.51 mps). Using the formula: $F = ma$, or $F = W/{-g} \cdot dv/dt$, we obtain

$$F = \frac{763}{(-32.2)} \cdot \frac{(-66.02)}{0.5} = 3128.77 \text{ lb } (1419.21 \text{ kg}) = \text{retarding force} \qquad (1)$$

where

$$W = (1430 - 667) \text{ or } 763 \text{ lb } (346.1 \text{ kg})$$

and

$$\frac{dv}{dt} = \frac{(-113.64) - (-47.62)}{0.5} \text{ or } \frac{-66.02 \text{ fps}}{0.5 \text{ sec}} \left(\frac{20.12 \text{ mps}}{0.5 \text{ sec}}\right)$$

$$F_o = F + W = 3128.77 \text{ lb} + 763 \text{ lb} = 3891.77 \text{ lb } (1765.3 \text{ kg})$$

$$\text{total deceleration force} \qquad (2)$$

$$\frac{F_o}{W} = \frac{3891.77 \text{ lb}}{763 \text{ lb}} = 5.1 \text{ G (gravitational force units)} \qquad (3)$$

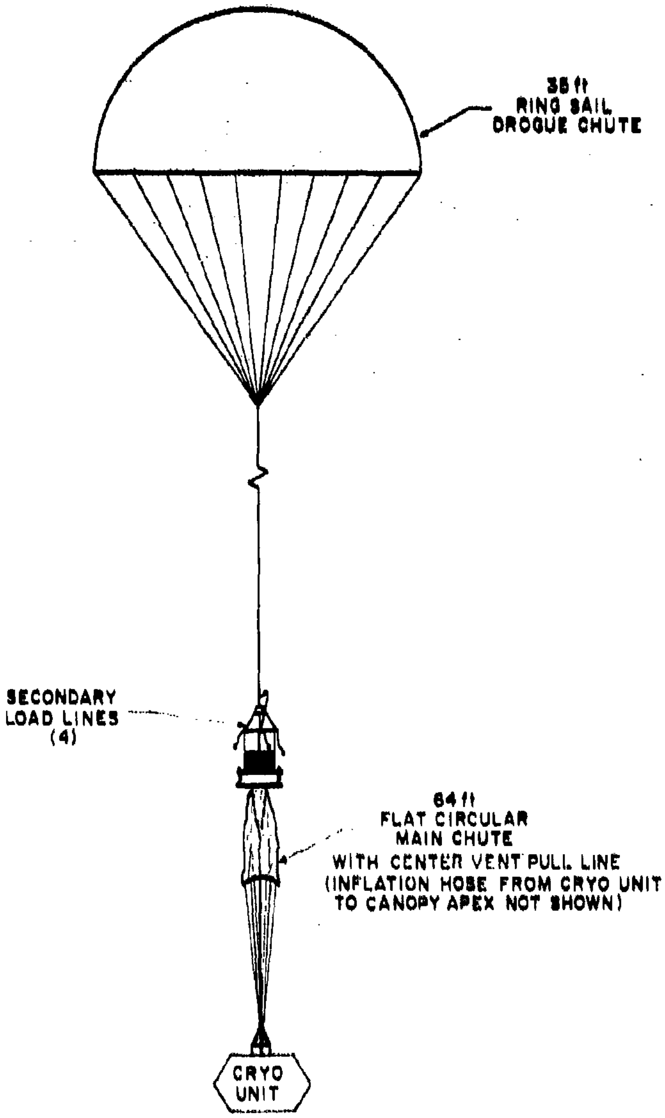

Figure 8. ALBS Flight Test: Main Chute Deployment

Table 4. Main Canopy Deployment Calculations (Selected Values)

Drogue					Free Falling Cryo Unit					
t (sec)	v fps	W lb	H ft	$\Sigma\Delta H_D$ ft	v (fps)	$\bar{v}$ (fps)	ΔH (ft)	$\Sigma\Delta H_C$ (ft)	H ft	$\Sigma\Delta H_C$ $-\Sigma\Delta H_D$
.0	-58.90	667	24072	0	-58.90	0	0	0	23872	0
.05	-57.26		24069.1	-2.9	-60.51	-59.71	-2.985	-2.985	23869.0	-.085
.15	-54.47		24063.51	-8.49	-63.78	-62.925	-3.146	-9.197	23862.8	-.707
.25	-52.18		24058.18	-13.82	-66.98	-66.14	-3.307	-14.731	23856.3	-1.011
.30	-51.20		24055.6	-16.40	-68.55	-67.76	-3.388	-18.119	23852.9	-1.719
1.00	-43.70		24022.9	-49.1	-91.1	-90.285	-4.5143	-75.00	23797	-25.9
1.50	-41.77		24001.6	-70.4	-107.2	-106.4	-5.320	-124.58	23747.4	-54.18
1.55	-41.65		23999.5	-72.5	-108.81	-108.01	-5.400	-129.98	23742.0	-57.48
1.60	-41.54		23997.43	-74.57	-110.42	-109.62	-5.481	-135.46	23736.5	-60.89
1.65	-41.43		23995.36	-76.64	-112.03	-111.23	-5.561	-141.02	23731.0	-64.38
1.70	-41.33		23993.29	-78.71	-113.64	-112.84	-5.64	-146.66	23725.7	-67.95
1.75	-42.08	1430	23991.20	-80.8						
1.80	-42.79		23989.08	-82.92						
1.85	-43.48		23986.93	-85.07						
1.90	-44.15		23984.74	-87.26						
1.95	-44.79		23982.51	-89.5						
2.00	-45.40		23980.26	-91.74						
2.05	-45.99		23977.97	-94.03						
2.10	-46.56		23975.66	-96.34						
2.15	-47.10		23973.32	-98.68						
2.20	-47.62		23970.94	-101.03						

Legend

- v — Vertical velocity
- W — Weight
- H — Height
- $\Sigma\Delta H$ — Sum of incremental height changes
- D — Drogue
- C — Cryogenics Unit
- t — Elapsed time

Notes:

1. Values on left hand side (drogue) are extracted from the event. 3a computation , Appendix A. Values on the right side, cryogenic unit, are based on the free-fall formulas shown on Table A. For calculation purposes time intervals are 0.05 sec. throughout, even though the display of selected values seems to indicate longer intervals.
2. The far right column ($\Sigma\Delta H_C - \Sigma\Delta H_D$) shows the difference in distance fallen, at a given elapsed time, between the drogue-supported components and the free-falling cryogenic unit.
3. Free fall ends when $\Sigma\Delta H_C - \Sigma\Delta H_D$ equals 65 ft, which is the length of the center vent pull line. The drogue then carries the full load again, accelerating towards a new equilibrium velocity. At t=2.20, i.e. 1.70 + .5 second, the cryogenic unit is assumed to have slowed to the drogue velocity. That velocity becomes the initial velocity for the main chute opening.
4. The above drogue initial-velocity value, -58.90 fps, was arbitrarily substituted in these calculations for the -58.87 fps value shown on Table 2 for the end of event 3b.

The arbitrary 0.5-sec deceleration time may be shorter than that to be observed in the actual test, in which case the error will be on the safe side. (With longer deceleration periods the G load is less.) The addition of ballast (note 10, Section 4.4.2) to the cryogenic unit will work in the other direction, however, and may serve to raise G loads above the design value of the cryogenic unit, 10G. The El Centro tests will resolve this point.

The next event, 3b, main canopy inflation (opening), involves a major assumption: Because the top of the main canopy is under tension, from the 967-lb (438.68 kg) pull of the drogue chute (cf Appendix A, Table A3) its opening time will not be that of an independently acting 64-ft parachute but rather that of a hypothetical, partially open larger parachute whose fully open area is the sum of the areas

of the main chute and the drogue chute. The "partially open" area is the area of the drogue chute alone. Under this assumption, the main canopy opening time is, then, the time that the hypothetical parachute, which is assumed to be carrying the entire suspended load, will take to increase its open area linearly from that of the drogue alone to a value equal to the summed areas of the drogue and main parachutes. With a 64-ft main chute and a 35-ft drogue chute, the respective individual parachute areas are 3217 ft^2 (298.9 m^2) and 962 ft^2 (89.4 m^2). The sum, 4179 ft^2 (388.3 m^2), is equal to $\pi D_o^2/4$, where D_o is the nominal diameter of the hypothetical chute. A parachute with this area has a D_o of 72.945 ft (22.23 m). For such a parachute, Table 2 shows an opening time of 3.5 sec, based on the above "partially-open" assumption. (See Appendix A, Table A3 for event 3b backup computations.) The hypothetical chute, which is the analogue equivalent of our two-chute array, reaches equilibrium velocity, -28.52 fps (-8.69 mps), approximately 2.8 sec later, thus completing event 3c. Opening shock is slight, only about 1.26 G.

The configuration at this time is essentially that shown on Figure 9. The system is now ready for the critical balloon extraction event. Note that the cumulative time for the events thus far is less than 25 seconds. The main canopy is roughly 1500 ft (457.2 m) below the original release altitude of 25,000 ft (7.62 km).

Before discussion of the balloon extraction event (Section 4.4.5) some qualifying remarks are in order with regard to the basic assumption outlined above concerning the opening of the main canopy. (These remarks will be relevant in the balloon extraction discussion, also.)

In postulating the "analogue equivalent" parachute, no consideration was allowed for possible distortion of the drogue as it became partially unloaded during the free-fall of the cryogenic unit and then picked up the whole load again when the center vent pull line became taut. It was treated as a stable, fully open chute throughout. Likewise no allowance was made for the likely penetration of the load on top of the main canopy into the opening-up folds of that canopy, seriously distorting the canopy geometry and normal opening characteristics. Thus, the standard reference areas, drag coefficients, porosity values and the like, used to get the values shown in Table 2, may have to be multiplied by one or more adjustment factors to obtain true performance values. Since factors of this type can be obtained only through tests such as those planned at El Centro, no attempt will be made here to guess at what they should be.

The possibility that ballast may be necessary to improve the opening performance of the 64-ft chute (main canopy) and to aid the ensuing balloon extraction process is another factor which makes vulnerable the velocities, times, and altitudes shown on Table 2 for the completion of various events. On the other hand, ballasting may help to eliminate the distortion problems suggested in the preceding paragraph, thereby justifying any recomputations that its use may entail. Even if no

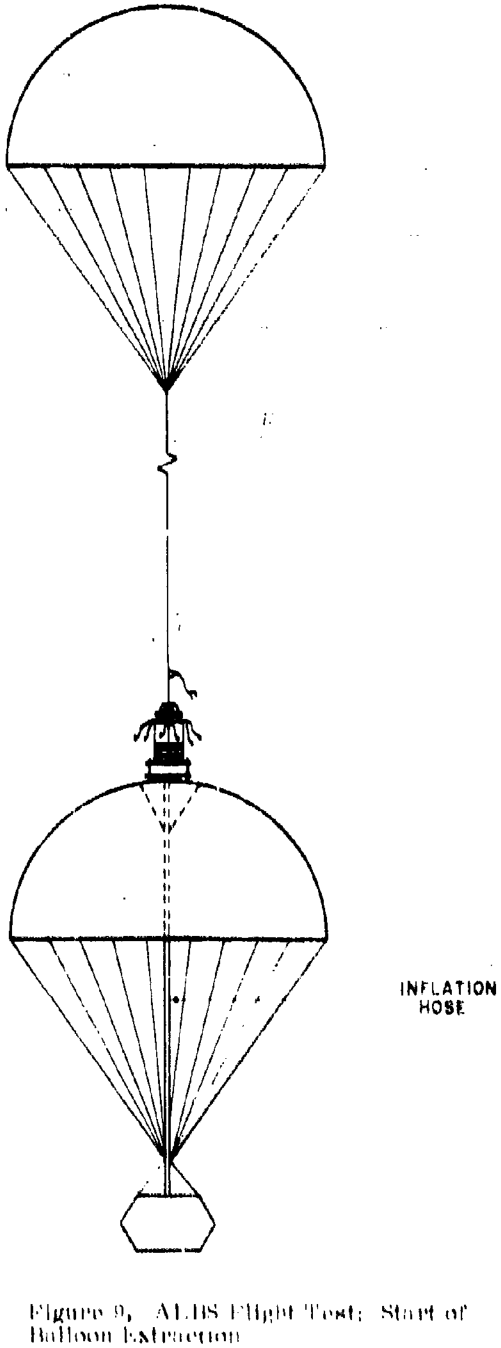

Figure 9. ALBS Flight Test: Start of Balloon Extraction

ballast weight value can be assigned at this time, it can be assumed that a ballasted system will fall faster, and will have larger opening shocks. It may also be a more predictable system, however, in terms of preventing excessive downward excursions of the apex load and of achieving the desired drag at the proper time.

These qualifying remarks having been stated, the discussion will now continue on the assumption that the times and other parameters given on Table 2 are reasonably valid.

4.4.5 BALLOON DROP EVENT NO. 4, ALBS BALLOON EXTRACTION

The balloon extraction event will begin as soon as the two-parachute array has reached an equilibrium velocity (-28.52 fps, -8.69 mps) as discussed in Section 4.4.4 (no ballast employed, standard factors used). A timer-generated signal will now fire a second Tenney release (event 4a). Four suspension lines, similar to those released from the carrier balloon in event 1a, will thereupon be disconnected from the drogue extension line (Figure 9). This quickly (0.5 sec) "unloads" the drogue once more; that is, drastically reduces the weight it is suspending.

Just prior to the firing of this 2nd Tenney release, the drogue, at event 3c equilibrium velocity, was supporting a load equal to the product of the total load, 1430 lb, and the ratio of the drogue's effective drag area to the total effective drag area of the array. A numerical example of this statement is presented.

Using the effective drag area values derived in note 16 we see that the drogue, just before the second release, was supporting the following weight:

$$1430 \text{ lb } (648.65 \text{ kg}) \times \frac{750.45}{3163.19} \text{ or } 339.26 \text{ lb } (153.88 \text{ kg}).$$

---

16. The effective drag area of a parachute is not the same as the area discussed in Section 4.4.4 and which is normally referred to as S_o, the reference area, where $S_o = \pi/4\, D_o^2$. The effective drag area is the product of the reference area and the parachute's coefficient of drag, C_D. Thus, using the average C_D values of 0.78 and 0.75 for the drogue and main parachutes, respectively, we obtain effective drag areas as follows:

<u>English Units</u>

$962.11 \text{ ft}^2 \times 0.78 = 750.45 \text{ ft}^2 = (C_D S_o)$ for the 35 ft dia. drogue chute

$3216.99 \text{ ft}^2 \times 0.75 = 2412.74 \text{ ft}^2 = (C_D S_o)$ for the 64 ft dia. main chute

$(C_D S_o)\text{drogue} + (C_D S_o)\text{main} = 3163.19 \text{ ft}^2 = (C_D S_o)$ for the 72.045 ft dia. combined chute.

<u>Metric Units</u>

$89.383 \text{ m}^2 \times 0.78 = 69.719 \text{ m}^2 = (C_D S_o)$ for the 10.67 m dia. drogue chute

$298.868 \text{ m}^2 \times 0.75 = 224.151 \text{ m}^2 = (C_D S_o)$ for the 19.51 m dia. main chute

$(+)\ 293.87 \text{ m}^2 = (C_D S_o)$ for the 22.23 m dia. combined chute

The remainder of the load (1430 lb - 339.26 lb or 1090.74 lb) was being supported by the main canopy (1090.74 lb = 494.76 kg).

When the release occurs (event 4a) the load on the drogue is suddenly reduced from 339.26 lb (153.88 kg) to approximately 70 lb (31.75 kg). (See notes 17 and 18.) The drogue then starts to decelerate rapidly. The unloaded weight is picked up by the main canopy which starts to accelerate. Main canopy loading jumps from 1090.74 lb (494.76 kg) to 1360 lb (616.9 kg). The net effect is that the two parachutes start to pull away from each other vertically. However, they are still joined loosely by the accordian-packed ALBS balloon, the top of which is still attached to the drogue extension line. (The base of the balloon is secured to the main canopy apex.) Since the drogue, even though decelerating, still has drag, it serves as an

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17. The 70 lb (31.75 kg) load on the drogue at the moment of separation is based on the assumption the drogue now supports only 10 percent of the balloon weight, that is, 10 percent of 180 lb or 18 lb, plus the weights of the extension line, the hardware attached thereto, and the drogue's own weight. The total weight of these other items is 52 lb. (Refer back to Table 1 for system weight values.) This is not a static load, however, and will increase, as the balloon is pulled out, from an initial 70 lb (18 + 52) to a final 232 lb (180 + 52). (In metric values the increase is from 31.75 kg to 108.235 kg.) A second assumption here is that this transfer of load back to the drogue will occur linearly over the time period required by the extraction process. By making this assumption we can program the gradual changes in speed of the two chutes and, thus, calculate the time required to extend the balloon to its full length. The changes in speed arise from the fact that, as the drogue gradually becomes loaded again, it starts to speed up. The main chute is gradually losing weight, of course, so that it is simultaneously decelerating. At the end of event 4b, the two chutes are moving apart at a speed of approximately 6.5 fps (1.98 mps) as noted on Table 2: (-29.69 fps) - (-23.21 fps). See Appendix A (Table A4 and A5) for computations of the performance of the two chutes during the extraction process.

18. The sudden unloading of the drogue at event 4a introduces once more the type of uncertainty discussed in Section 4.4.4 in connection with main chute deployment. The drogue may not simply decelerate, that is, reduce its rate of descent. It may even move upward and become distorted as its suspension lines and the 200-ft extension line relax. Thus, instead of a smooth, linear-with-time withdrawal of the balloon from its storage container there may be a series of uneven pulls and possibly some lateral displacement at the same time. The reefed, accordion-pleated balloon material is expected to survive a reasonable amount of rough treatment in this regard, but overall system stability may be marginal. The El Centro tests will attempt to resolve this uncertainty by extracting a simulated ALBS balloon (a 102-ft length of heavy rope) from a container on top of the main canopy.

"anchor" in the sky to support the top end of the ALBS[1] balloon, thus effectively pulling it up from its storage compartment on top of the main chute.[19]

The above extraction event (4b) requires 9 sec, the time it takes the two chutes to move apart by 102 ft, which is the length of the special ALBS balloon. When the fully extended balloon (Figure 10) is taut the coupled two-chute array is in effect again and a new equilibrium velocity is attained in 3 sec (-28.20 fps, -8.60 mps). This completes event 4x. The balloon is now ready for the inflation process, event 5.

19. If we examine the behavior of the 35-ft diam. drogue during the extraction process, in the calculations of Appendix A (Table A4) it is clear that q, the dynamic pressure, quickly drops to a very low value, 0.11 psf (0.537 kg/m^2). Ideally, according to the Parachute Handbook, q should not dip below 0.5 or 0.3 psf (2.44 or 1.46 kg/m^2). Even with the assumption that the drogue does not become seriously distorted or displaced at event 4a, there is still a question of whether it will remain inflated at such low q values. For this reason a ring slot chute, with a lower coefficient of drag (0.55), may actually be a better choice as a drogue chute (see note 20).

The main chute's q (Appendix A, Table A5) hovers around 0.5 psf throughout the extraction, but in the calculations no provision was made for possible distortions of canopy geometry as the apex load pushes down on that relatively slow-moving (≈29 fps) chute.

Since the dynamic pressure, q, is a function of atmospheric density and system velocity ($q = 1/2 \rho V^2$), for a given altitude, q can be increased by increasing system velocity. This is where the attractiveness of ballasting the load under the 64-ft chute lies. By increasing that load the main chute will be made to fall faster (see formula, note 20 below) and to build up "q", thus resisting the tendency of the apex load to sink into the canopy and to distort its geometry. (On the other hand, the uncertainty mentioned in note 18, regarding the unloading of the drogue, may be exacerbated by ballasting, since the loss of weight experienced by the drogue in event 4a is thereby increased.)

20. Equilibrium velocity, that is, the velocity of the descending system in the steady state condition is determined by the formula below. (Note that V_e increases with increased weight and/or decreased C_D. Per note 19, increased V_e means a higher value of q.)

$$V_{e_H} = \left(\frac{W}{\frac{\rho_{MSL}}{2} \cdot \sigma_H \cdot (C_D S_O)_{max}} \right)^{1/2}$$

where W = the weight of the system, including the parachute,

ρ_{MSL} = mean sea level density

σ_H = ratio of the density at altitude H to that at MSL

V_{e_H} equilibrium velocity at altitude H. This is called the terminal velocity when altitude H is at ground level

C_D coefficient of drag of the parachute

S_O = reference area of the parachute $\frac{\pi D^2}{4}$

$(C_D S_O)_{max}$ maximum effective area of the parachute

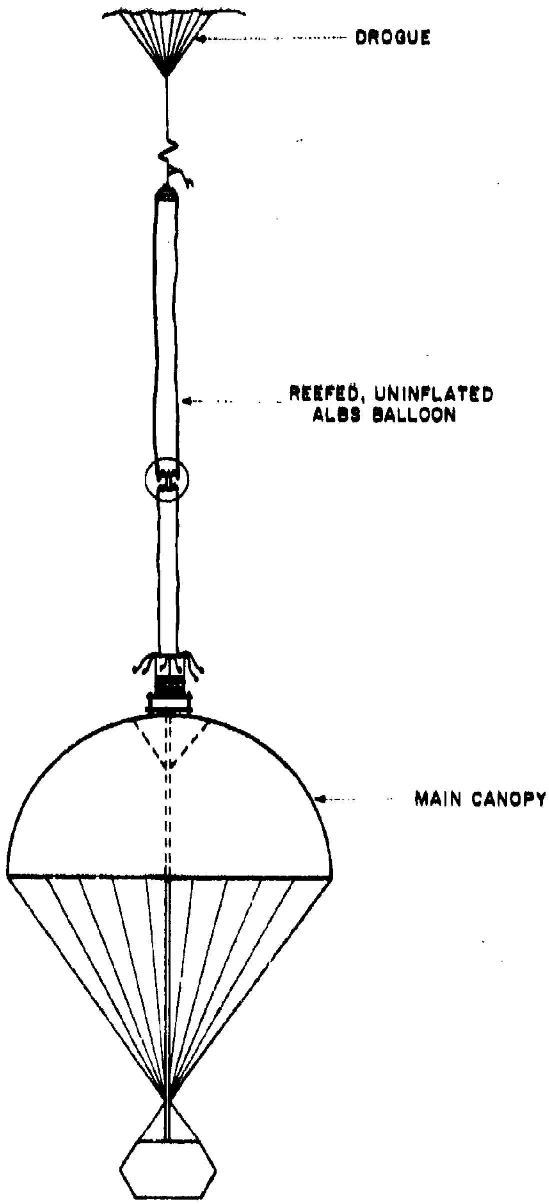


Figure 10. ALBS Flight Test: Completion of Balloon Extraction

4.4.6 BALLOON DROP EVENT NO. 5, BALLOON INFLATION

At the end of event 4c the balloon has been fully extended and is taut (see Figure 10). If we assume that the uninflated balloon contributes no effective drag, the total system drag area is the same as it was before the extraction, 3163.19 ft^2 (293.86 m^2), which is the sum of the effective drag areas of the drogue and the main chute. (The balloon is treated here as just an added line between the two chutes.) The drag force on the drogue is then 339.26 lb (153.88 kg) as calculated in Section 4.4.5, and that on the main chute is 1090.74 lb (494.76 kg).

When the balloon inflation command is now given, the process begins whereby the liquid helium in the cryogenic unit below the main canopy is converted to the gaseous state, warmed and transferred up to the waiting balloon. Although the gas starts to flow almost instantaneously the complete event is a long one, requiring an estimated five min for transfer of all of the gas. During all of this time the ALBS array is losing altitude steadily, but at a decreasing rate of descent.

Two interesting and interacting physical changes occur simultaneously during the inflation process, both of which have a pronounced effect on the dynamics of the event.

First, as the liquid helium changes over to gas and enters the balloon it adds buoyancy (positive lift) to the system, neutralizing some of the weight previously supported by the parachutes. Thus, there is a steady diminution of system weight (W_S) apparent on Table 5, which lists changes in various system parameters during the balloon inflation. (The incremental loss of W_S is matched by the increase in $\Sigma\Delta L$, buoyancy.) Because W_S is decreasing there is an accompanying decrease in system descent velocity, per the relationship shown in note 20 in the preceding section. This can be observed in the column headed V_e on Table 5. (Not all of the deceleration shown in the V_e column is the result of the added buoyancy. Some is due to increased system drag, as explained in the next paragraph, and to increasing atmospheric density.)

A second change is that the gas bubble formed at the top of the balloon adds to the total effective drag area of the system $(C_DS_o)_S$. It will be seen from Table 5 that $(C_DS_o)_S$ increases throughout the inflation process until the drogue cutaway action. At that point, there is a step decrease to show the loss of (C_DS_o) for the drogue. The reduced $(C_DS_o)_S$ value then becomes the starting point for a new incrementally-increased system effective drag area, the augmentation of which persists until the balloon is fully inflated. (The incremental increases in $(C_DS_o)_S$ are equal numerically to the increases shown under the $(C_DS_o)_B$ column.)

H (ft)	σ	P_2 (Atm)	Air Temp°K	L/M Ratio	Δt (sec)	$\Sigma\Delta t$ (sec)	V_e (fps)	q (psf)	$\Sigma\Delta$MHe (lb)	$\Sigma\Delta$L (lb)	W_s (lb)	V_s ft^3	(f
23400	.47444	.3892			—	—	-28.20	—	—	—	1430	—	
200	.47775	.4016	259	5.993	7.13	7.13	-27.90	.4422	2.426	14.538	1415.46	496.35	9
23000	.48108	.4051			7.212	14.342	-27.56	.4346	4.879	29.242	1400.76	989.73	12
800	.48442	.4086			7.299	21.641	-27.242	.4275	7.361	44.12	1385.88	1480.32	14
600	.48779	.4121			7.383	29.024	-26.933	.4207	9.873	59.167	1370.83	1968.51	15
400	.49117	.4156			7.468	36.492	-26.63	.4142	12.413	74.39	1355.60	2454.25	16
200	.49457	.4192	261	5.940	7.552	44.044	-26.34	.4080	14.983	88.99	1341.0	2936.87	17
22000	.49708	.4227			7.636	51.680	-26.04	.4016	17.581	104.43	1325.57	3417.68	18
800	.50142	.4263			7.723	59.403	-25.75	.3954	20.209	120.04	1309.96	3895.30	19
600	.50487	.4300			7.810	67.213	-25.46	.3893	23.866	135.83	1294.17	4369.58	20
400	.50834	.4336			7.899	75.112	-25.18	.3831	25.554	151.79	1278.21	4842.58	20
200	.51183	.4373	263	5.887	7.087	83.099	-24.90	.3775	28.272	166.44	1263.56	5312.32	21
21000	.51534	.4410			8.077	91.175	-24.62	.3715	31.020	182.62	1247.38	5779.83	22
800	.51887	.4447			8.170	99.345	-24.34	.3655	33.709	198.08	1231 02	6245.25	22
600	.52241	.4485			8.265	107.61	-24.06	.3595	36.611	215.53	1214.47	6707.40	23
400	.52597	.4523			8.362	115.97	-23.78	.3535	39.455	232.27	1197.73	7167.73	23
200	.52956	.4561	265	5.835	8.458	124.43	-23.52	.3482	42.332	247.01	1182.99	7626.41	24
20000	..53316	.4599			8.556	132.99	-23.24	.3423	45.243	263.99	1161.01	8083.40	24
800	.53678	.4638			8.660	141.65	-22.96	.3363	48.187	281.17	1148.83	8537.02	25
600	.54042	.4677			8.766	150.41	-22.67	.3304	51.167	298.56	1131.44	8989.36	25
400	.54407	.4716			8.875	159.29	-22.39	.3244	54.183	316.16	1113.84	9440.59	26
200	.54775	.4755	267	5.784	8.520	176.81	-24.555	.3927	57.237	331.06	1056.94	9890.89	26.
19000	.55144	.4795			8.107	176.01	-24.24	.3853	60.168	348.02	1039.98	10310.76	27
800	.55516	.4835			8.303	184.31	-23.94	.3782	62.989	364.33	1023.67	10704.84	27
600	.55889	.4875			8.409	192.72	-23.63	.3712	65.846	380.86	1007.14	11098.55	27
400	.56265	.4915			8.518	201.23	-23.33	.3640	68.740	397.59	990.41	11491.96	28
200	.56642	.4956	269	5.734	8.623	209.86	-23.06	.3582	71.671	410.96	977.03	11882.85	28
18000	.57021	.4997			8.730	218.59	-22.76	.3511	74.368	427.97	960.03	12273.25	28
800	.57402	.5038			8.849	227.43	-22.45	.3439	77.642	445.20	942.80	12663.33	28
600	.57785	.5080			8.972	236.41	-22.14	.3368	80.687	462.66	925.34	13051.16	29
400	.58170	.5122			9.098	245.51	-21.83	.3295	83.774	480.36	907.64	13439.39	29
200	.58557	.5164	271	5.684	9.218	254.72	-21.56	.3238	86.904	493.97	894.03	13828.23	29
17000	.58946	.5206			9.342	264.07	-21.25	.3165	90.076	512.00	876.00	14217.33	30
800	.59337	.5249			9.482	273.55	-20.93	.3092	93.291	530.27	857.73	14604.10	30
600	.59730	.5292			9.627	283.18	-20.614	.3018	96.554	548.81	839.19	14992.05	30
400	.60125	.5335			9.778	292.95	-20.29	.2944	99.867	567.64	820.36	15381.44	30
200	.60522	.5370	273	5.635	9.902	302.86	-20.03	.2887	103.23	581.71	806.28	15769.60	31
16000	.60921	.5422			10.068	312.94	-19.70	.2812	106.645	600.95	787.05	16161.86	31

Table 5. ALBS Balloon Inflation Calculations

W_S (lb)	V_B ft^3	d_B (ft)	$(C_D S_O)_S$ (ft^2)	$(C_D S_O)_B$ $(ft)^2$	D_B (lb)	D_D (lb)	D_M (lb)
1430	—	—	3163.19	—	—	339.26	1090.74
1415.46	496.35	9.824	3201.09	37.90	16.757	331.84	1066.87
1400.76	989.73	12.365	3223.22	60.03	26.09	326.13	1048.53
1385.88	1480.32	14.140	3241.71	78.52	33.569	320.83	1031.49
1370.83	1968.51	15.55	3258.14	94.52	39.95	315.74	1015.14
1355.60	2454.25	16.74	3273.18	109.99	45.55	310.80	999.28
1341.0	2936.87	17.77	3287.17	123.98	50.58	306.15	984.27
1325.57	3417.68	18.69	3300.35	137.16	55.09	301.41	969.06
1309.96	3895.30	19.52	3312.85	149.66	59.18	296.74	954.03
1294.17	4369.58	20.28	3324.77	161.58	62.89	292.11	939.16
1278.21	4842.58	20.99	3336.22	173.03	66.29	287.52	924.30
1263.56	5312.32	21.65	3347.24	184.05	69.48	283.29	910.79
1247.38	5779.83	22.27	3357.89	194.70	72.33	278.78	896.28
1231.02	6245.25	22.85	3368.20	205.01	74.93	274.28	881.82
1214.47	6707.40	23.40	3378.20	215.01	77.30	269.78	867.39
1197.73	7167.73	23.92	3387.92	224.73	79.45	265.31	852.97
1182.99	7626.41	24.42	3397.41	234.22	81.56	261.31	840.13
1161.01	8083.40	24.90	3406.68	243.49	83.34	256.86	825.81
1148.83	8537.02	25.36	3415.70	252.51	84.93	252.40	811.50
1131.44	8989.36	25.80	3424.55	261.36	86.35	247.94	797.15
1113.84	9440.59	26.22	3433.22	270.03	87.61	243.47	782.77
1056.94	9890.89	26.63	2691.29	278.55	109.39	0	947.54
1039.98	10310.76	27.00	2699.12	286.38	110.34		929.64
1023.67	10704.84	27.34	2706.37	293.63	111.06		912.61
1007.14	11098.55	27.68	2713.53	300.79	111.64		895.81
990.41	11491.96	28.00	2720.59	307.85	112.07		878.34
977.03	11882.85	28.31	2727.54	314.80	112.76		864.27
960.03	12273.25	28.62	2734.39	321.65	112.93		847.10
942.80	12663.33	28.92	2741.17	328.43	112.96		829.84
925.34	13051.16	29.21	2747.85	335.11	112.85		812.40
907.64	13439.39	29.50	2754.46	341.72	112.60		795.03
894.03	13828.23	29.78	2761.02	348.28	112.77		781.25
876.00	14217.33	30.06	2767.52	354.78	112.30		763.70
857. 3	14604.10	30.33	2773.93	361.18	111.68		746.04
839.19	14992.05	30.59	2780.29	367.56	110.94		728.24
820.30	15381.44	30.86	2786.63	373.89	110.07		710.29
806.28	15769.60	31.11	2793.90	380.16	109.75		696.54
787.05	16161.86	31.37	2799.17	386.43	108.66		678.39

← **Cut away drogue here.**

LEGEND

H	altitude
σ	atmospheric density ratio (ρ/
P	atmospheric pressure
L/M ratio	lift/mass ratio lb. lift / lb. gas
Δt	time differential
$\Sigma\Delta t$	cumulative differential
V_s	system equilibrium descent
q	dynamic pressure
$\Sigma\Delta MHe$	cumulative quantity of Heliu
$\Sigma\Delta L$	cumulative buoyancy added
W_S	over-all system loading on pa
V_B	volume of gas bubble
d_B	diameter of gas bubble
$(C_D S_O)_S$	total effective drag area
$(C_D S_O)_B$	effective drag area of gas
D_B	drag of balloon
D_D	drag of drogue
D_M	drag of main chute

Note 1. $D_B + D_D + D_M = D_S = W_S$ at Equilibrium

Note 2. Temperature of He(g) assumed 250 °K

Table 5. ALBS Balloon Inflation Calculations

$_DS_O)_s$ (t^2)	$(C_DS_O)_B$ $(ft)^2$	D_B (lb)	D_D (lb)	D_M (lb)
163.19	—	—	339.26	1090.74
201.09	37.90	16.757	331.84	1066.87
23.22	60.03	26.09	326.13	1048.53
241.71	78.52	33.569	320.83	1031.49
258.14	94.52	39.05	315.74	1015.14
273.18	109.99	45.55	310.80	999.25
287.17	123.98	50.58	306.15	984.27
3300.35	137.16	55.09	301.41	969.06
3312.85	149.66	59.18	296.74	954.03
3324.77	161.58	62.89	292.11	939.16
3336.22	173.03	66.29	287.52	924.39
3347.24	184.05	69.48	283.29	910.79
3357.89	194.70	72.33	278.78	896.28
3368.20	208.01	74.93	274.28	881.83
3378.20	215.01	77.30	269.78	867.39
3387.92	224.73	79.45	265.31	852.97
3397.41	234.22	81.56	261.31	840.13
3406.68	243.49	83.34	256.86	825.81
3415.70	252.51	84.93	252.40	811.50
3424.55	261.36	86.35	247.94	797.15
3433.22	270.03	87.61	243.47	782.77
2691.29	278.55	109.39	0	947.54
2699.12	286.38	110.34	↓	929.64
2706.37	293.63	111.06		912.61
2713.53	300.79	111.64		895.51
2720.59	307.85	112.07		878.34
2727.54	314.80	112.76		864.27
2734.39	321.65	112.93		847.10
2741.17	328.43	112.96		829.84
2747.85	335.11	112.85		812.49
2754.46	341.72	112.60		795.03
2761.02	348.28	112.77		781.25
2767.52	354.78	112.30		763.70
2773.93	361.18	111.68		746.04
2780.29	367.56	110.94		728.24
2786.63	373.89	110.07		710.29
2793.90	380.16	109.78		696.54
2799.17	386.43	108.66		678.39

← Cut away drogue here.

LEGEND

H	altitude
σ	atmospheric density ratio (ρ/ρ_o)
P	atmospheric pressure
L/M ratio	lift/mass ratio lb. lift / lb. gas
Δt	time differential
$\Sigma\Delta t$	cumulative differential
V_s	system equilibrium descent velocity
q	dynamic pressure
$\Sigma\Delta M_{He}$	cumulative quantity of Helium transferred
$\Sigma\Delta L$	cumulative buoyancy added to system
W_s	over-all system loading on parachutes
V_B	volume of gas bubble
d_B	diameter of gas bubble
$(C_DS_O)_t$	total effective drag area
$(C_DS_O)_B$	effective drag area of gas bubble (balloon)
D_B	drag of balloon
D_D	drag of drogue
D_M	drag of main chute

Note 1. $D_B + D_D + D_M = D_s = W_s$ at Equilibrium Velocity

Note 2. Temperature of He(g) assumed 250 °K throughout

The increased drag area associated with the developing gas bubble $(C_D S_o)_B$ serves to decrease system equilibrium descent velocity, V_e. As noted above, additional deceleration is being caused simultaneously by the buoyancy and atmospheric density effects. Thus, the values of column V_e reflect the combined reductions in system descent velocity. Table 5 shows that as the system equilibrium velocity, V_e, decreases, q (dynamic pressure) also decreases, as does the total system drag or decelerating force, D_s. (See notes 21 and 22.) There is a step increase in q, when the drogue is cut away, but the decrease soon continues.

Table 5 shows changes in system parameters over fixed intervals of height (200 ft). The starting altitude of 23,400 ft approximates the altitude of the drogue chute at the end of event 4c on Table 2 (23,463 ft). The starting equilibrium velocity is the system V_e at the end of event 4c. A program was developed (see Figure 11) to ascertain the time required for the system to fall through each 200-ft interval of height, taking into effect the decreasing velocity because of factors discussed above. Incremental and cumulative time values are shown under columns Δt and $\Sigma\Delta t$ respectively.

It was assumed that the total quantity of helium, 102 lb, would be transferred linearly with time over 300 sec (5 min). On that basis, the amount transferred (ΔMHe) during any 200-ft interval would be a function of the time (Δt) required to descend that distance. Whence, $\Delta MHe = \Delta t \cdot \frac{102}{300}$. For example, during the first 200-ft interval on Table 5 (23,400 ft - 23,200 ft) the amount of helium transferred is 2.426 lb, which is the result of the calculation 7.05 sec $\times \frac{102}{300} \times 1.012$, where

21. The actual step-by-step drag forces on the three drag-developing components, the balloon, the drogue chute and the main chute, are shown in columns D_B, D_D, and D_M respectively. D_S, the sum of those three columns for each step, equals the corresponding W_S. (D_S is not shown separately on Table 5.) Note that, despite the steady increase of D_B, the sum of D_B, D_D, and D_M decreases in step with W_S. (See note 22.) This is as it should be, since, in a parachute system at equilibrium velocity, $W_S = D_S$, which is a simple rearrangement of the equation in note 20, Section 4.4.5. The component drag values are included in Table 5 to allow monitoring of the performance of those components and to enable the drogue cutaway point to be established with confidence.

22. D, drag, is a function of both q and the effective drag area, that is, $D = q(C_D S_o)$. In this situation the decrease in q means a decrease in total system drag (decelerating) forces, despite the increasing values of $(C_D S_o)_S$ because of the predominant effect of q which decreases with the square of the velocity ($q = 1/2\rho V^2$).

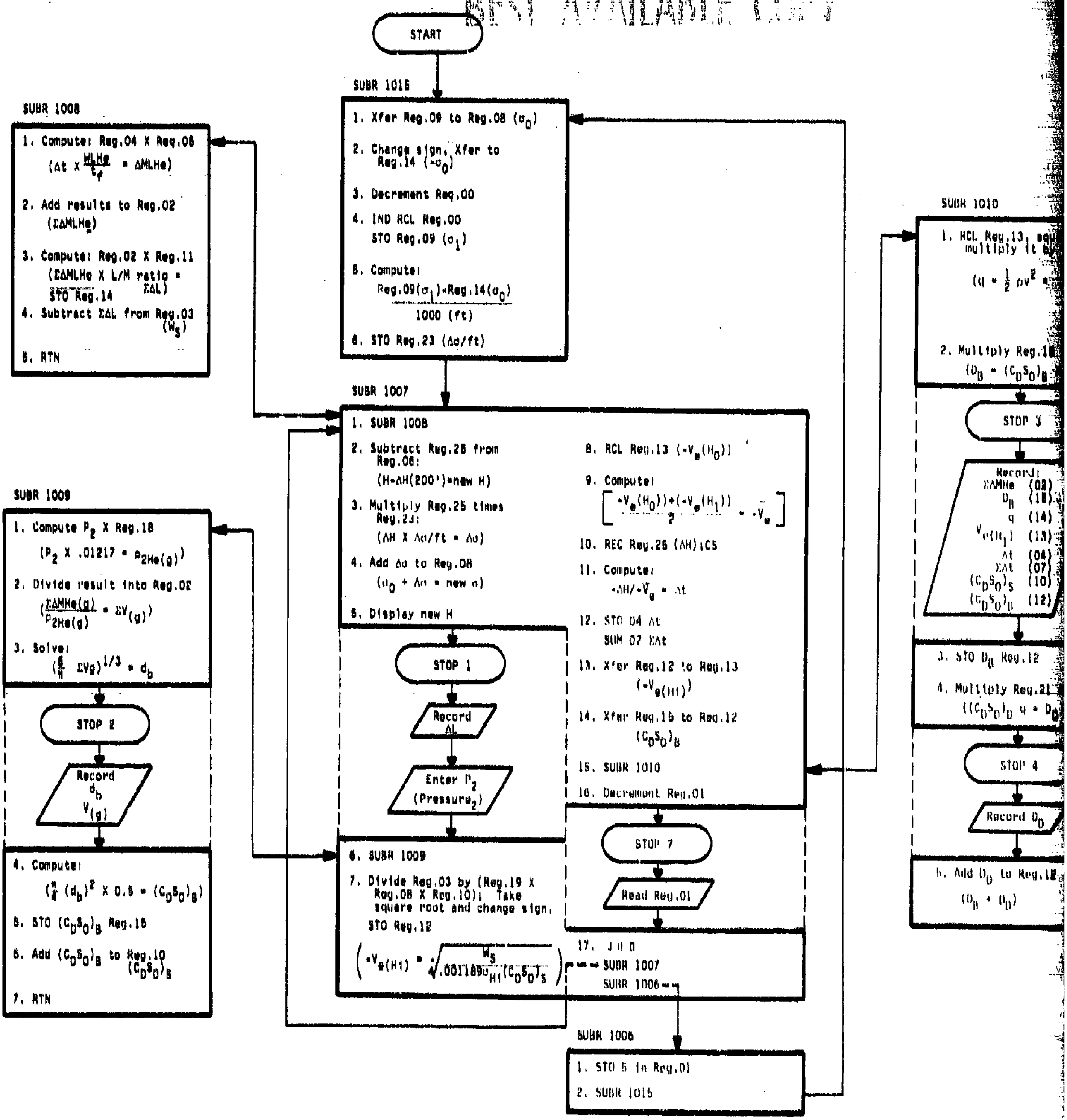
7.05 sec is the estimated Δt for the first interval and 1.012 is an empirical correction factor. (See note 23.) This quantity appears in the $\Sigma\Delta MHe$ column which is a cumulative record of the amount of helium transferred as the event proceeds. When the quantity of helium (lb) is multiplied by the lift to mass (L/M) ratio (lb lift per lb of mass) for helium at the pressures and temperatures involved the amount of buoyancy is obtained. Cumulative values of buoyancy appear in the $\Sigma\Delta L$ column.

The density of helium (at 250°K) is calculated for each 200-ft altitude increment by the program used for Table 5. This density value is divided into the $\Sigma\Delta MHe$ value to obtain the volume occupied by the gas, V_b.[24] The gas volume is assumed to be that of a sphere, whence the diameter, d_b, is obtained by the relationship $d_{sphere} = (V \frac{6}{\pi})\ 1/3$. Knowing the diameter, we can obtain the cross-sectional area ($\pi d^2/4$) or S_o. This is then multiplied by a value of 0.5 (C_D for the bubble) to give us $(C_DS_o)_B$ or the effective drag area of the balloon; $(C_DS_o)_B$ in turn augments the value of $(C_DS_o)_S$.

---

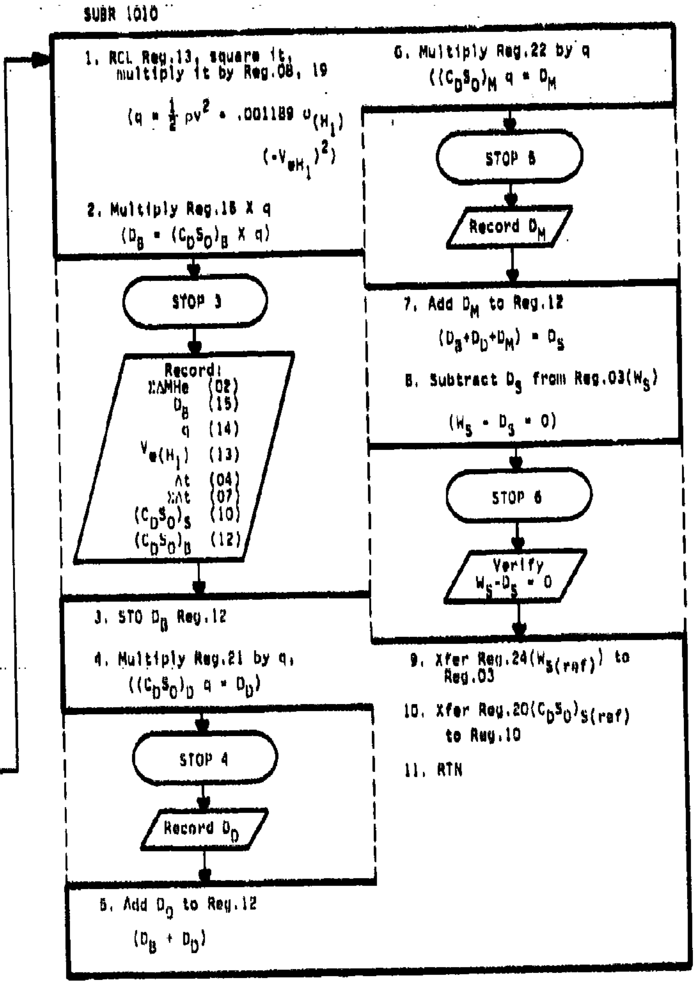
23. The actual descent time for each 200-ft interval is a function of the system velocity, which in turn, is a function of the changes being generated by the developing gas bubble. The program used an educated guess (7.05 sec) as the Δt for the first ΔMHe calculation. The actual Δt was 7.13 sec, derived from a knowledge of the system configuration after the gas bubble had formed. (The gas bubble here is the product of the estimated amount of helium transferred, based on the estimated Δt.) For the 2nd ΔMHe calculation, the 7.13 sec value was used as the estimated Δt, yielding a ΔMHe value of 2.453 lb, which when added to the 2.426 lb from the first interval calculation yields a $\Sigma\Delta MHe$ of 4.879 lb. Because the system is slowing down, the Δt values, are increasing with each interval. Hence the use of the previous intervals Δt in each ΔMHe calculation leads to an understatement of the amount of gas transferred. This is the reason for the use of the empirical correction factor, to ensure that 102 lb of helium are actually transferred when $\Sigma\Delta t = 300$ seconds.

24. The lift to mass ratio is obtained by dividing the specific lift of gaseous helium (density of air-density of helium) by the density of helium. Air and helium densities were separately calculated for 1000 ft intervals, assuming an air temperature varying between 259° and 273°K and a constant helium temperature of 250°K. The resulting L/M ratios are shown on Table 5. The values were assumed to hold constant throughout the 1000 ft interval and then jump to a new value. This assumption generates slight inaccuracies but the values obtained are considered adequate for the purposes of this report. More accurate helium densities, calculated for each 200 ft, are used in the determination of the volume of the gas in the bubble, V_b. (See Addendum.)



START
SUBR 1015
1. Xfer Reg.09 to Reg.08 (σ0)
2. Change sign, Xfer to Reg.14 (-σ0)
3. Decrement Reg.00
4. IND RCL Reg.00
STO Reg.09 (σ1)
5. Compute:
Reg.09(σ1)-Reg.14(σ0) / 1000 (ft)
6. STO Reg.23 (Δσ/ft)
SUBR 1008
1. Compute: Reg.04 X Reg.08
(Δt X MLHe/tf = ΔMLHe)
2. Add results to Reg.02
(ΣΔMLHe)
3. Compute: Reg.02 X Reg.11
(ΣΔMLHe X L/M ratio = ΣΔL)
STO Reg.14
4. Subtract ΣΔL from Reg.03 (WS)
5. RTN
SUBR 1007
1. SUBR 1008
2. Subtract Reg.25 from Reg.06:
(H-ΔH(200')=new H)
3. Multiply Reg.25 times Reg.23:
(ΔH X Δσ/ft = Δσ)
4. Add Δσ to Reg.08
(σ0 + Δσ = new σ)
5. Display new H
STOP 1
Record ΔL
Enter P2 (Pressure2)
6. SUBR 1009
7. Divide Reg.03 by (Reg.19 X Reg.08 X Reg.10); Take square root and change sign.
STO Reg.12
(-Ve(H1) = -√(WS / .001189σH1(CDSO)S))
8. RCL Reg.13 (-Ve(H0))
9. Compute:
[(-Ve(H0))+(-Ve(H1)) / 2 = -V̄e]
10. REC Reg.25 (ΔH);CS
11. Compute:
+ΔH/-V̄e = Δt
12. STO 04 Δt
SUM 07 ΣΔt
13. Xfer Reg.12 to Reg.13
(-Ve(H1))
14. Xfer Reg.15 to Reg.12
(CDSO)B
15. SUBR 1010
16. Decrement Reg.01
STOP 7
Read Reg.01
17. J ≠ 0
SUBR 1007
SUBR 1006
SUBR 1009
1. Compute P2 X Reg.18
(P2 X .01217 = ρ2He(g))
2. Divide result into Reg.02
(ΣΔMHe(g) / ρ2He(g) = ΣV(g))
3. Solve:
(6/π ΣVg)^1/3 = db
STOP 2
Record db V(g)
4. Compute:
(π/4 (db)² X 0.5 = (CDSO)B)
5. STO (CDSO)B Reg.15
6. Add (CDSO)B to Reg.10 (CDSO)B
7. RTN
SUBR 1006
1. STO 5 in Reg.01
2. SUBR 1015
SUBR 1010
1. RCL Reg.13, square, multiply it by
(q = ½ ρv²
2. Multiply Reg.1
(DB = (CDSO)B
STOP 3
Record:
ΣΔMHe (02)
DB (15)
q (14)
Ve(H1) (13)
Δt (04)
ΣΔt (07)
(CDSO)S (10)
(CDSO)B (12)
3. STO DB Reg.12
4. Multiply Reg.21
((CDSO)D q = DD)
STOP 4
Record DD
5. Add DD to Reg.12
(DB + DD)

SUBR 1010



Registers

00	Count	(34)
01	Count	(5) Notes 3, 4
02	$\Sigma\Delta MHe$	0
03	$W_S 0,1,2$	1430
04	$\Delta t_{0,1,2}$	7.06 (est.)
05	$WLHe/t_f$	.3441 (Note 5)
06	$H_0/H_{1,2}$	23400
07	$\Sigma\Delta t$	0
08	σH_0	0
09	$\sigma_{H_0} / \sigma_{(H_0 - 1000')}$	.47444
10	$(C_D S_0)_S 0,1,2$	3163.19
11	L/M ratio	5.993 (note 4)
12	0	--
13	$-V_{e_{H_0}} / -V_e$	-28.20
14	working	--
15	working	--
16	0	--
17	0	--
18	See Note 2	.01217
19	See Note 5	.001189
20	$(C_D S_0)_{S(ref)}$	3163.19
21	$(C_D S_0)_D$	750.45
22	$(C_D S_0)_M$	2412.74
23	$\Delta\sigma/ft$	0 (Note 3)
24	$W_{S(ref)}$	1430
25	$\Delta H(ft)$	200
26	$\sigma_8(15.4kft)$	.62138
27	$\sigma_7(16.4kft)$	.60125
28	$\sigma_6(17.4kft)$	.58170
29	$\sigma_5(18.4kft)$	.56266
30	$\sigma_4(19.4kft)$	.54407
31	$\sigma_3(20.4kft)$	.52597
32	$\sigma_2(21.4kft)$	.50834
33	$\sigma_1(22.4kft)$	.49117

1. This is a cyclic open-en
limitations of the Wang
display only) of data
It will be noted that th
The 18 registers beyond
from the programming st
the stops can be elimina
addendum)

2. The computation for the

is based on the relation

If ρ_1 for He at 1 Atm an
at a given altitude, is

Table 5 shows the value

3. Atmospheric density is

from standard atmosphere
etc.) is the density at
account for changing de
the initial value of σ
fallen (ΔH) and the diff
The Δσ/ft parameter is
and every 5th cycle the
SUBR 1007, op.17.) Ini
subtracted from σ_1, the
starting altitude and d
indirect recall method,
is decremented and a ne
to recall σ values stor

4. Stop 7 is used to moni
L/M ratio for each 1000

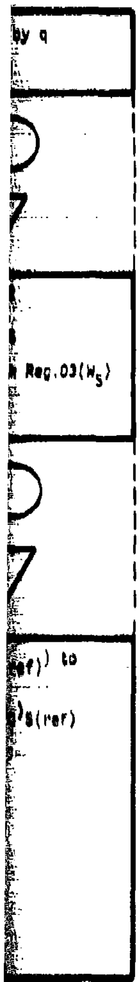
5. The number .001189 in R

6. The number .3441 in Reg

.3441 lb He
sec

7. When the drogue is cut
(from 1430 to 1388 lb)
extension line and the
in Reg.24 and 03 to be
A similar change is re
the loss of the drogue
chute, 2412.74 ft². T
$(C_D S_0)_S$ value is that
each iteration to get
values of ΔL are subtr

Figure 11. Flow Diagram for Program



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Registers

00	Count	(34)
01	Count	(5) Notes 3, 4
02	$\Sigma\Delta MHe$	0
03	$W_S 0,1,2$	1430
04	$\Delta t_{0,1,2}$	7.05 (est.)
05	$WLHe/t_f$	.3441 (Note 6)
06	$H_0/H_{1,2}$	23400
07	$\Sigma\Delta t$	0
08	σH_0	0
09	σ_{H_0} / $\sigma_{(H_0-1000')}$	.47444
10	$(C_D S_0)_S 0,1,2$	3163.19
11	L/M ratio	5.993 (note 4)
12	0	--
13	$-V_{e_{H_0}}/-V_e$	-28.20
14	working	--
15	working	--
16	0	--
17	0	--
18	See Note 2	.01217
19	See Note 5	.001189
20	$(C_D S_0)_{S(ref)}$	3163.19
21	$(C_D S_0)_D$	750.45
22	$(C_D S_0)_M$	2412.74
23	$\Delta\sigma$/ft	0 (Note 3)
24	$W_{S(ref)}$	1430
25	ΔH(ft)	200
26	σ_8(15.4kft)	.62138
27	σ_7(16.4kft)	.60125
28	σ_6(17.4kft)	.58170
29	σ_5(18.4kft)	.56265
30	σ_4(19.4kft)	.54407
31	σ_3(20.4kft)	.52597
32	σ_2(21.4kft)	.50834
33	σ_1(22.4kft)	.49117

NOTES

1. This is a cyclic open-ended program, set up to operate within the performance limitations of the Wang 452-1 Scientific Desk Calculator: No printout (i.e., display only) of data; 320 steps of programming; 16 permanent registers (0-15). It will be noted that the program actually uses registers from 0 to 33. The 18 registers beyond the permanent registers were obtained by borrowing from the programming steps at the cost of eight steps per register. Many of the steps can be eliminated through the use of a more powerful calculator.(See addendum)

2. The computation for the density of helium (g) in subroutine 1009, op.1, is based on the relationship $\rho_2 = \rho_1 \times \frac{T_1}{T_2} \times \frac{P_2}{P_1}$

   If ρ_1 for He at 1 Atm and 59°F (288°K) is .01056 lb/ft^3 then ρ_2 for 250°K He at a given altitude, is equal to $.01056 \times \frac{288}{250} \times \frac{P_2}{1} = .01217\ P_2$

   Table 5 shows the values of P_2 used, expressed in ATM.

3. Atmospheric density is computed by the use of σ, where $\sigma = \frac{\rho}{\rho_0}$ and is obtained from standard atmosphere tables. The density at a particular altitude (H_0, H_1, etc.) is the density at MSL times σ for the altitude. The procedure to account for changing density as the system descends each 200 ft is to augment the initial value of σ with a $\Delta\sigma$ value which is the product of the distance fallen (ΔH) and the difference in σ per foot, $\Delta\sigma$/ft. (See SUBR 1007 op.3.) The $\Delta\sigma$/ft parameter is determined in SUBR 1015 at the start of the first cycle and every 5th cycle thereafter. (This is the reason for the JIFO step in SUBR 1007, op.17.) Initially, σ_0, the σ for the event starting altitude is subtracted from σ_1, the σ for the altitude 1000' below the event starting altitude and divided by 1000. (σ_1, is recalled from Reg.33 by the indirect recall method.) With each 1000' of descent (ΔH or 200' X 5) Reg.00 is decremented and a new, lower-by-one indirect recall command is generated, to recall σ values stored in Reg.32, 31, 30, etc. in succession.

4. Stop 7 is used to monitor the count in Reg.01 and to insert a new value of L/M ratio for each 1000 ft of descent.

5. The number .001189 in Reg.19 is equal to $\frac{1}{2}\rho_{MSL}$, where ρ_{MSL} = .002738 slugs/ft^3.

6. The number .3441 in Reg.05 = $\frac{102 \text{ lb He}}{300 \text{ sec}}$ X 1.012 (correction factor) = .3441 $\frac{\text{lb He}}{\text{sec}}$

7. When the drogue is cut away the reference system weight is decreased by 42 lbs (from 1430 to 1388 lb). (The 42 lb includes the weight of the drogue, the extension line and the hardware on the line.) This requires the value of W_S in Reg.24 and 03 to be changed to 1388 before the program is resumed. A similar change is required for Reg.20 and 10, since $(C_D S_0)_S$ is decreased by the loss of the drogue, $(C_D S_0)_D$. The new reference $(C_D S_0)_S$ is that of the main chute, 2412.74 ft^2. The value of $(C_D S_0)_D$ in Reg.21 goes to 0. (The reference $(C_D S_0)_S$ value is that to which the cumulative values of $(C_D S_0)_B$ are added with each iteration to get the new $(C_D S_0)_S$ value. (In the case of W_S, the cumulative values of ΔL are subtracted from the reference W_S.)

Figure 11. Flow Diagram for Program P14-B, Inflation of Balloon (Event 5)

As the balloon fills, the expanding bubble causes the reefing sleeve to open up gradually in such a way that slack material is still protected. Because of the relatively low altitude, the size of the bubble (d_B) remains small, reaching a maximum diameter of only 31 ft at full inflation. The volume of gas in this bubble, approximately 16,000 ft^3, is only 10 percent of the fully-expanded volume at float altitude. Moreover, although the volume is increasing by virtue of added gas, the rate of increase is slowed by the effect of increased atmospheric density as the system descends.

At some point the drogue must be cut away, both to eliminate unnecessary weight from the system which will rise to float altitude and to avoid possible entanglement when the drogue becomes very lightly loaded and subject to collapse. Table 5 indicates that the drogue is cut away when the buoyant lift in the balloon is 318 lb, which is more than enough to keep the balloon upright after the support furnished heretofore by the drogue is removed.

The inflation is shown to be complete before the system has descended to 16,200 ft. (Completion is indicated when 102 lb of helium have been transferred to the balloon.) Interpolation indicates that the final height is approximately 16,270 ft. However, since the reference starting height of event 5 (23,400 ft) was related to the altitude of the now-missing drogue, the altitude of the balloon is approximately 200 ft lower or 16,070 ft. For the purposes of this report the completion height for event 5 will be entered as 16,000 ft.

The balloon (Figure 12) is now ready to be cut away from the apex of the main canopy and to ascend to float altitude with its payload.

4.4.7 EVENTS 6 and 7 BALLOON SEPARATION AND ASCENT

Early in this report (note 6, Section 2.3) it was stated that the LHe quantity— 102 lb (46.27 kg), was that needed to lift 575 lb (260.82 kg) and to provide 10 percent free lift besides. Using a L/M ratio of 6.245 for He (based on equal air and gas pressures and temperatures) 102 lb of helium will provide 636.99 lb of lift (288.94 kg). This is more than 575 + 57.5 or 632.5 lb (286.40 kg) required. However, Table 5 indicates that the total lift at the end of event 5 is just about 575 lb, which means that there is very little free lift. This is a result of the 250°K temperature assigned to the gas, vs the 259 to 273°K range assigned to the atmosphere. (The air temperatures are typical of the White Sand Missile Range (WSMR) environment median values.) Note that the L/M ratios entered on Table 5 are all below 6.245.

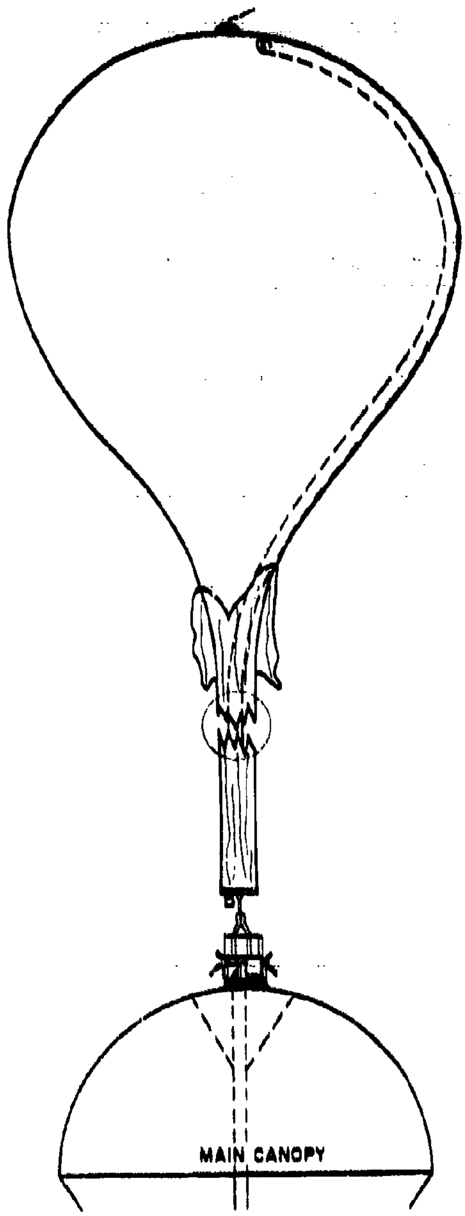

Figure 12. ALBS Flight Test: Completion of ALBS Balloon Inflation (Balloon and payload start to pull away from main canopy)

The message here is clear relative to the planned balloon drop: If warm air temperatures are expected, the amount of helium used must be increased slightly or the gross load must be decreased, in order to preserve free lift (see note 25). Assuming that the necessary precautions are taken and that there is adequate free lift, we can be sure that separation of the balloon and its payload will occur when the restraining cable shown in Figure 7b is severed. The balloon system is expected to lift up from the apex of the main canopy and to ascend to float altitude at a rate of rise of approximately 800 fpm (Figure 13). Ascent time should be about 68 minutes. The main canopy and the cryogenic system will descend to the ground at WSMR in about 12 min with a terminal velocity of approximately 17 fps.

4.4.8 OTHER EVENTS

The purpose of this report has been to examine the mid-air deployment and inflation sequences of the ALBS system in great detail. This it has done. There are other events, for example, launch of the carrier balloon, cutdown and recovery of the ALBS balloon and payload, recovery of the carrier balloon, which are important to the success of the over-all test program, but which will not be covered in this report. Those events are believed to be fairly routine in nature and to involve standard procedures.

Similarly no details will be given of command and control systems, sensors, telemetry packages and the like which must be employed during the tests to ensure their success and to provide adequate diagnostic data. While the systems to be employed for these purposes will require custom planning, they will be made up for the most part of standard flight communications and control devices. The author is heavily dependent on his colleagues at AFGL for assistance in these vital areas.

25. The assumption that the temperature of the gas remains constant at 250°K is conservative. There are two processes in effect to warm the gas: (1) the transfer of thermal energy from the balloon envelope as it is warmed by solar and terrestial radiation and by contact with the ambient air, and (2) the adiabatic warming of the gas (4°K/1000 ft) as it descends. These factors have not been computed because of the impossibility of knowing the precise temperature of the gas as it enters the balloon at any point during the inflation process. The 250°K figure is an estimated average instantaneous temperature of the gas. It may very well be too low, in which case, buoyancy is enhanced. A model is being developed to take these processes into account and it will be incorporated into the program at a later date.

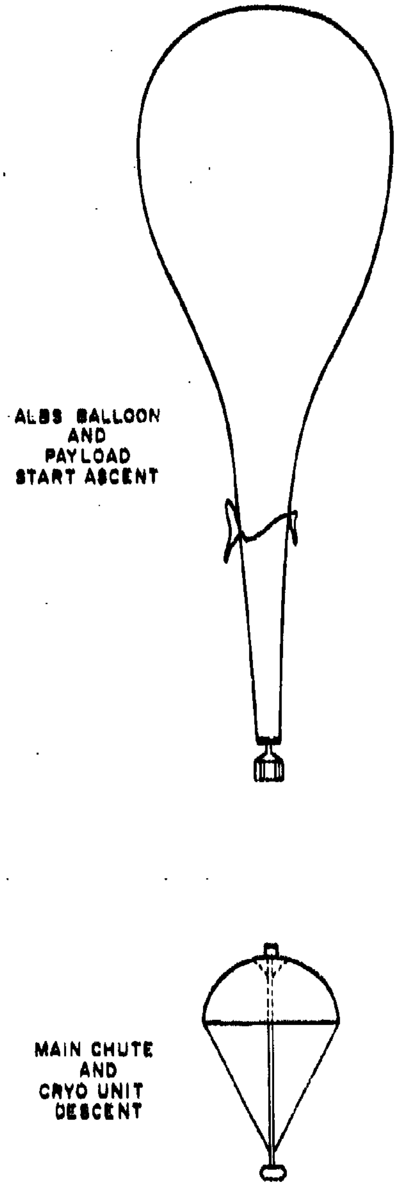

Figure 13. ALBS Flight Test: ALBS Balloon and Payload Ascent, Main Chute and Cryogenic Unit Descent

5. SUMMARY AND CONCLUSIONS

The Air Launched Balloon System development history has been traced and the circumstances leading up to the tests now in planning have been described. The theoretical performance of a typical deployment system (35-ft ring sail drogue, 84-ft flat circular main chute) has been analyzed using a number of stated assumptions and employing programs developed for this purpose. Contingency arrangements, (for example, use of ballast) and their impact have also been discussed. Data presented indicate that the ALBS concepts are basically sound but require experimental verification to ensure optimum component selection. Such verification is the anticipated result of the tests planned in the fall of 1976 at El Centro and in the spring and summer of 1977 at WSMR.

Appendix A

Tables A1 Through A6

A1. GENERAL

Tables A1 through A6 of this Appendix contain summations of back-up English-unit data generated in the compilation of Table 2, main text. The data are presented in the format employed by the author on his computational worksheet. The listed program numbers (P4U, P-13A, etc.) refer to programs first prepared by him for use on a scientific desk calculator (Wang model 452-1) and later adapted to a programmable pocket calculator (Texas Instruments SR-52) for away-from-the-office use. (See Figures A1 through A6 for flow diagrams.)

To avoid confusion, it is suggested that the reader first find the subject listed on a particular sheet (for example, events 2a and 2b, on Table A1) and then relate the computational sheets to the data for the events on Table 2 and to the discussion of the events in the main text.

In general, programs labeled P4U are concerned with the opening phase of parachute performance, over the time period from T = 0 to T = 1.0, and with the attainment of equilibrium velocity immediately afterwards. The primary output of Program P4U is the new system descent velocity at time, t. (Several additional parameters are derived simultaneously to give a more complete picture.) The associated programs (P-9, P-7U, P-10) are used to verify the opening time selected for use in P4U and to determine opening shock values. The programs are based on procedures outlined in the Parachute Handbook.[13] The P-13A programs are aimed at tracking fully-open parachutes as loading conditions are varied.

The discussion which follows is concerned with the rationale behind the data sheets and their associated programs and is presented as being of possible interest to the reader. The method used for explanation will be to examine the key features of one or more worksheets in considerable detail with the hope that a coherent picture will emerge.

A2. CALCULATIONS FOR PARACHUTE OPENING PROCESS (PROGRAM P-4U)

A2.1 Selection of Opening Time

If we examine the worksheet for events 2a and 2b, opening of 35-ft ring sail drogue chute (Table A1), we note that a filling (opening) time, t_f, of 3.5 sec has been selected. This is a key input to Program P4U. Normally, as in the case of the event 3b computations, Table A3, this selection involves trial and error until a reasonable value of t_f is obtained, as verified by the computations of Programs P-0 and P7U. (See notes A1 and A2.)

However, in the case of the 35-ft ring sail drogue we are dealing with a parachute with geometric porosity, that is, porosity which is a function of openings in the canopy. ("Solid" canopies, such as the 64-ft flat circular main parachute, lack such openings and rely on the porosity [air permeability] of the material used in their construction.) The fact of geometric porosity eliminates the normal trial and error selection of t_f here and allows the use of the handbook method explained in the

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A1. Program P-0 solves Eq. (12-11) in the Parachute Handbook:

$$\frac{dV}{dT} = f(T,\ t_f) = \frac{D_o^2 t_f v}{\pi}\left((1-T)\ (T^{4/3}) - 2cT\ (1-T) \right)$$

for values of T from 0 to 1.0, using the velocity values obtained from Program P-4U. (T is equal to t/t_f, that is, is the ratio of elapsed time to total filling time, and dV refers to the change in system volume as the parachute opens.) Program P-0 also computes the maximum theoretical volume for the size of parachute, where

$$V_{max} = \frac{2D_o^3}{3\pi^2} = .06755\ D_o^3.$$

A2. Program P7U effectively plots the dV/dT values (obtained by Program P-0) against T, from T = 0 to T = 100, and measures the area under the resultant curve. The answer, which is really a volume, is compared against V_{max}. If reasonably close, the selected t_f is accepted and Program P-10 is run. (See note A3.) If not, a new value of t_f is selected and the process is repeated, substituting the new t_f in Program P4U to generate a new set of velocity values.

note on Table A1 to obtain t_f directly. Velocity values generated by Program P4U from this t_f are then used to derive opening shock values (see note A3). Height and velocity values shown on Table A1 at the end of events 2a and 2b have been transferred to Table 2 in the main text, and, in the case of 2b, form the starting conditions for the next event, 3a.

It can be seen, then, that the computation described on the P4U worksheet serves several purposes. It determines opening shock and end-of-event time, height and vertical velocity values. It monitors dynamic pressure and drag forces throughout the event. It also permits easy determination of the attainment of system equilibrium velocity and the impact of changing various input parameters such as drag coefficient, chute diameter and system weight.

A3. Program P-10 uses the velocity values obtained from Program P-4U to solve the following equations, for values of T from 0 to 1:

$$\frac{dv}{dT} = \frac{-22.5v}{A'+22.5T} - \frac{B't_f Tv^2}{A'+22.5T} + \frac{C't_f}{A'+22.5T} \qquad (1)$$

where

$$A' = \frac{W \cdot 10^5}{\sigma g D_o^3}$$

(cf. Parachute Handbook, Eq. 12-10)

$$B' = \frac{120(C_D S_o)_{max}}{D_o^3}$$

$$C' = A'g$$

$$F = \frac{-W}{g t_f}\frac{dv}{dT} = \text{Total retarding force} \qquad \text{(Eq. 12-12)} \qquad (2)$$

$$F_o = W + F = \text{Opening shock force} \qquad (3)$$

$$\frac{F_o}{W} = \text{Opening shock force in units of g} \qquad (4)$$

Note that the maximum calculated opening shock force (Table A1) is 2,143 g's.

A2.2 Calculation Interval

Program P4U relies for its success on a large number of calculations performed iteratively. With the selection of a t_f of 3.5 sec, the parameter $t_f/50$ is fixed at 0.07 sec. (See Table A1, register 02.) This is the time interval between successive calculations of new descent velocities (Section A2.4). In developing program P4U, the author found it to work best when iterations were carried out at intervals of $t_f/50$ or even shorter (for example, $t_f/200$ when t_f is large). (See note A4.) On Table A1, under column t, the values entered are 0.35, 0.70, etc., which are five-fold multiples of 0.07. This simply means that although the calculations were made at $t_f/50$ intervals of 0.07 sec (or 0.02T) they were recorded on the worksheet only at intervals of $5 \times t_f/50$ or when T = 0.1, 0.2, 0.3 etc. Thus, the reader is advised that the first value in the Δv column does not represent the difference between the initial velocity, v_i, and the velocity at T = 0.1. Rather it represents the difference between the velocity at T = 0.1 and that at the iteration T = 0.08, just preceding.

A2.3 Development of Reference Area

Program P4U assumes that the parachute reference area, S_o, is at a minimum at time 0. In this case the minimum area value, b, is 2.5 ft^2. The program proceeds to increase the reference area linearly with each iteration until a maximum is attained at T = 1.0. (Table A1 shows calculated opening areas at T values of 0.1, 0.2, etc.) When T is greater than 1.0, the area is treated as a constant.

A2.4 Development of Velocity Values

The initial velocity, v_i (=145 fps) is obtained from the previous event (ie, the end of the first free fall period). The -151.78 fps velocity on Table A1 at T = 0.1 (t = 0.35) was computed by the method about to be described. (The same method holds for T = 0.2, 0.3, etc.)

The basic assumption in the determination of a new descent velocity is that $v_1 = v_i + \Delta v_1$. Knowing v_i (or v_o) it is easy to arrive at v_1 if we can find Δv_1. Recalling the formulas of Table 3, main text, we know that in a free-falling system

A4. The calculations and programs discussed here "work" in the sense that they produce values which one might logically expect in the analysis of an opening parachute, taking into consideration the effects of increased reference area, increased drag, reduced velocity, etc. They are based on techniques given in the Parachute Handbook, but they have not been verified to date against actual parachute openings.

$\Delta v = -gt$ and is constant for a given time interval. The formula for Δv in a descending parachute system is a modification of this formula which takes into consideration the deceleration forces generated by the canopy:

$$\Delta v = -g\delta t \left(1 - \frac{D}{W}\right)$$

where

- W = system weight, which is known and is a constant;
- D = system drag, which is determined by the equation, $D = q,\ (C_D S_o)_{max}$. [D in the case of an opening parachute is highly variable, because $(C_D S_o)$ changes linearly with time and because q, dynamic pressure, is also changing $(q = \frac{1}{2} \rho V^2)$.]
- g = -32.2 ft/sec^2 (gravitational constant)
- δt = incremental time (sec) (known)
- C_D = drag coefficient, known, treated as a constant

To solve for Δv we must know the value of D for each iteration. This, in turn, requires a knowledge of the instantaneous value of $(C_D S_o)$, which is obtained from the program, and of q. To track q we must know changes in atmospheric density (easily programmable) with each increment of time and also changes in velocity. This is a "Catch 22" situation in that we have to know beforehand what we are solving for (velocity) in order to solve for it. The program attempts to get around this dilemma by employing two velocities, a preliminary or estimated velocity, by which to derive a value of q, and a "final" velocity which is obtained using the value of q as derived. The values of $-v$ on the worksheet (Table A1) are the final velocities. (They are used later in programs P-9 and P-10.)

In the first iteration (T = 0.02) the preliminary velocity is obtained by assuming that the parachute system free falls for the period of $t_f/50$ or 0.07 sec. Preliminary Δv_1, for this calculation, is simply $-gt$, that is, -32 (rounded-off gravitational constant) $\times$ 0.07 or -2.24 fps. This is referred to as Δv_o. The preliminary v_1 is: $v_1 + \Delta v_o$, that is, (-145 fps + (-2.24 fps)) or -147.24 fps. The program then solves for the final v_1, using q, D, etc., developed from the preliminary value of v_1. In the course of the solution a final Δv_1 is also developed $(v_1 = v_1 + \Delta v_1)$.

In the second iteration (T = 0.04) Δv_o is recalled and added to Δv_1 in the empirically determined relationship:

$$\Delta v_{2\,(prelim.)} = (2\Delta v_1 - \Delta v_o)\,.$$

From $\Delta v_{2(prelim.)}$ a value for $v_{2(prelim.)}$ is obtained, thence a final value for v_2.

In succeeding iterations the preceding final Δv is added to the final Δv just obtained, in the manner shown above; for example,

$$\Delta v_{3(prelim.)} = (2\Delta v_2 - \Delta v_1)$$

and

$$v_{3\,(prelim.)} = v_2 + \Delta v_{3\,(prelim.)}$$

As stated earlier, only each 5th calculation is actually recorded on Table A1.

A2.5 Development of Other Parameters

The program also determines distances travelled vertically ($-\Delta H$) during a given time interval (and accumulates same) to enable altitude to be known at all times and to assist in the generation of needed atmospheric density data. Values of dynamic pressure, q, drag (D), and height obtained during these calculations appear in the columns so marked.

A2.6 Equilibrium Velocity

In the upper right-hand corner of Table A1 the value 59.638 has been inserted opposite $V_{e(H_i)}$. This is the absolute value of the theoretical equilibrium velocity (calculated by program P-40) for the system at the initial altitude, H_i (24,874 ft). This calculation is for reference purposes only. It indicates approximately the V_e which will be achieved after the chute is fully open. Table 2 (in the main text) shows that V_e is reached at 24,072 ft, and is -58.87 fps. If we use the region of constant q as the means of identifying V_e, the worksheet shows that V_e could have been selected as early as at t = 9.10 sec, when v = 58.94 fps and H = 24,113 ft. (In the actual experiment, it is likely that equilibrium will be considered to have been achieved even earlier in the event.)

A3. CALCULATIONS FOR FULLY OPEN PARACHUTES

A3.1 General

The other type of worksheet in this Appendix involves the use of Program P-13A. It tracks descending parachutes which are fully inflated, that is, $(C_D S_o)$ is at a maximum and remains constant. This accounts for the lack of an area column on the worksheet. Also, there is no reference to Programs P-9, P-70 or P-10 since the computations performed by those programs are inapplicable here.

There are three new columns on this worksheet which do not appear on the P4U sheet: W, V_e, and $\Sigma\Delta H$; W refers to system weight, which is a variable in these calculations (see Section A3.3); V_e refers to the projected equilibrium velocity (see Section A3.4) and $\Sigma\Delta H$ refers to the cumulative changes in height since time 0.

There are 4 P-13A worksheets in the Appendix, covering events 3a, 4b, (2 sheets) and 4c. The program was developed basically for event 4b and has been adapted slightly for use in events 3a and 4c. Event 4b (Tables A4 and A5) is the balloon extraction process which is described in detail in the main text (Section 4.4.5). In this event the drogue chute is suddenly unloaded from 339 lb to 70 lb, and then gradually loaded up again. The opposite action (sudden loading up, gradual unloading) occurs simultaneously in the case of the main chute. These weight changes greatly alter the velocities of the two chutes and permit them to pull apart. By monitoring $\Sigma\Delta H$ for both chutes one can determine the point in time when they are 102 ft apart, which is the length of the extracted balloon. In addition, a study of the D column, particularly in the case of the drogue chute, shows whether it is exerting the drag necessary to pull the balloon up steadily. Dynamic pressure (q), velocity (v), and height (H) are also monitored.

A3.2 Calculation Interval Time

The term filling time t_f, appears on this sheet, even though the parachutes are fully inflated. In this case, t_f is retained as a computational convenience. It really refers to the time required to extract the balloon and to extend it vertically to its full length. It is assumed that there will be a linear (with time) increase in the loading of the drogue chute as the balloon is pulled up from its storage location at the apex of the main chute. The selected value of t_f defines, therefore, the time required for the drogue loading to go from 70 lb to 232 lb. [At the higher weight the drogue supports 100 percent of the balloon weight (180 lb) plus 52 lb of other components. (See Section A3.3.)] The t_f value on Tables A4 and A5 was determined by trial and error to be approximately 9 sec, whence the iteration interval, $t_f/50$, of 0.18 sec. (See note A5.)

A5. The values displayed in Tables A4 and A5 are not consistently those associated with simple 5X multiples of the iteration interval (5 x .18), as was the case with the Program P-4U worksheet (see Section A2.2). Initially, when large changes are occurring, the values are recorded as computed, that is, for every successive iteration. During the section labeled "Longer Intervals" data are indeed presented at multiples of the iteration interval, because changes per iteration are slight. The data presentation frequency returns to the iteration frequency as t approaches t_f, however, because of the importance of the final moments of the extraction.

A3.3 The Weight Computation

The 70-lb weight on the drogue (Table A4) immediately after the unloading occasioned by event 4a is made up of 10 percent of the balloon weight (18 lb) and 52 lb of "other component" weight. The 52 lb figure remains constant throughout the extraction process. The program adds 1/50th of the residual balloon weight, that is, 1/50 of (180-18) or 0.02×162 lb with each new iteration, so that W is increasing by increments of 3.24 lb per iteration, until, when $t = t_f$ or $T = 1.0$, W is at 232 lb. (On Table A5 a similar but opposite computation is carried out, as the weight on the main chute is linearly decreased.)

A3.4 Projected Equilibrium Velocity

The initial velocity (-28.37 fps) shown on Table A4 was associated with the loading on the drogue (330 lb) just before event 4a. The drastic reduction in loading (330 lb to 70 lb) caused by event 4a calls for a sharp reduction in drogue velocity. The program computes a new system velocity, therefore, referred to as the "Projected Equilibrium Velocity," V_{e1}, using the formula of note 20, Section 4.4.5, main text; V_{e1} (12.031 fps) is based on the 70-lb weight and the atmospheric density of the starting altitude (23,722 ft). It is expressed as an absolute value, that is, without the minus sign normally used in this report for rates of descent. This is the velocity to which (theoretically) the drogue would decelerate if the 70-lb load remains constant. However, since we have assumed that the drogue loading will increase with time as the balloon is extracted, it is impossible for V_{e1} to be attained, and the trend will be towards acceleration. Even so, it is not a useless computation because it makes possible the determination of the actual drogue velocity (-v) at the end of the first iteration. The computation is repeated for V_{e2}, V_{e3}, etc., from which $-v_2$, $-v_3$, etc., are obtained. (See next section.) From the step-by-step computation of these velocity values the program calculates the distance travelled (-ΔH) vertically per iteration, and, by summing the ΔH values, shows how far the system has fallen when $t = t_f$. A similar calculation is carried out on Table A5, the difference being that the main chute is losing weight, after an initial sudden increase, and consequently it is tending to decelerate. The change of weight is linear with time, as in the case of the drogue, and the amount of weight transferred per iteration is the same as on Table 4.

By comparing the ∑ΔH values for both the drogue and the main chute, we can tell whether or not they have separated by 102 ft. Note on Table A4 that ∑ΔH for the drogue at 9.0 sec is -169.42 ft, whereas, on Table A5 we see a ∑ΔH value of -274.39 ft. The difference of -104.47 ft indicates that we have exceeded our end point of 102 ft and that 9 sec is actually a little too long. (At 8.82 sec the separation is 103.79 ft, but not all the weight has been transferred.)

A3.5 The Velocity Calculation

The usefulness of the projected equilibrium velocity (V_e) calculation will now be explained. On the assumption that the drogue and main chutes remain stable subsequent to event 4a, a further assumption is made that the parachute will take 1/2 sec to go from its initial velocity ($-v_i$) to V_{e1}. (The latter assumption which also calls for W to remain constant during this interval, is a bold one, but appears justified on an empirical basis.) Thus, if the system goes from $-v_i$ to V_{e1} in 1/2 sec

$$\Delta v/\text{sec}_{(\text{instantaneous})} = 2(V_{eo} + V_{e1}) \text{ where } -v_i = V_{eo}$$

and

$$\frac{\Delta v}{\text{sec}}(t_f) = 2(V_{eo} + V_{e1})(t_f) = \Delta v_{1\,(\text{prelim.})} = \Delta v_o$$

whence:

$$-v_{1\,(\text{prelim.})} = -v_i + \Delta v_o .$$

The program uses the above computations to solve for $-v_{1\,(\text{prelim.})}$. From that basis it proceeds to solve for Δv_1 and $-v_1$ final as was done in Program P-4U (see Section A2.4). Once $-v_1$ final has been determined (along with q, D, H, $-\Delta H$) the program computes a new projected equilibrium velocity Ve_2, using the augmented weight for the drogue (the decreased weight for the main chute) and the appropriate atmospheric density for the new lower altitude. Ve_2 then serves to determine $-v_2$ in the manner described above. This process is repeated until the 50th iteration, when $t = t_f$.[A6]

A6. The counting number shown in Register 11 at the base of the forms governs the number of iterations performed.

A3.6 Tables A2 and A6

Table A2 is constructed in a manner similar to Tables A4 and A5, with one major exception. The weight on the drogue remains constant, subsequent to the unloading which occurs in event 3a, until the center vent pull line becomes taut. At that point there is a step change to the full system weight, which again remains constant with time. It can be seen that the values of V_e do not vary greatly once the weight has been established.

Table A6 also employs an unvarying weight. It has been included to bridge the gap between the extraction process and the balloon inflation process. The assumption here is that the drogue quickly accelerates to the main chute velocity[A7] when the balloon is fully extended and that the array, now treated as our hypothetical 72.945-ft diam chute, takes 3.0 sec to reach equilibrium velocity.

A7. If we examine Table A4 we note that the drag value for the drogue at $t = t_f$ or 9 sec (225.55 lb) is less than the 232 lb weight which it is supposed to be supporting. This is because the drogue has not fully accelerated by the end of the allocated time. With the base of the balloon still attached to and supported by the apex of the main canopy there is enough drag for the drogue to extend the balloon vertically until it becomes in essence a line between the two parachutes. When the line becomes taut, the drogue is accelerated to main chute velocity and develops 330 lb of drag as before.

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Table A1. Opening of 35-ft Ring Sail Drogue Chute, Events 2a and 2b

Date: 7/30/76

	Program P4U							Program P9	Program P10			
ft² AREA	(t/t_f) sec T	sec t	psf q	fps Δv	fps v	lb D	ft H	ft³ $f(T,t_f)$	fps/sec $\frac{dv}{dt}$	lb F	lb F_o	$\frac{F_o}{W}$ g
b. 2.5	0	0		-	V_i 145		24874	0	+ 98.52	+1249.01	180.08	.126
108.46	.1	.35	12.57	- .7570	144.75	940.72	24821.00	See Note Below	+ 25.04	- 305.94	1130.26	.788
194.42	.2	.70	12.28	+ .6826	144.16	1863.07	24766.64		- 47.11	+ 600.32	2030.32	1.420
290.38	.3	1.05	11.22	+1.752	144.35	2541.41	24716.78		- 98.44	+1240.12	2670.12	1.874
386.35	.4	1.40	9.64	+2.320	133.67	2005.12	24667.06		-124.00	+1574.46	3004.46	2.101
482.31	.5	1.75	7.973	+2.474	121.46	2907.20	24623.40		-128.78	+1633.08	3063.08	2.143
578.27	.6	2.10	6.476	+2.380	109.15	2920.07	24583.02		-120.40	+1528.80	2958.86	2.069
674.23	.7	2.45	5.248	+2.004	98.37	2754.21	24546.70		-106.27	+1348.36	2778.36	1.943
770.19	.8	2.80	4.278	+1.707	88.79	2569.99	24513.99		- 90.50	+1140.46	2570.46	1.804
866.15	.9	3.15	3.535	+1.511	80.67	2388.63	24484.37		- 75.82	+ 963.02	2392.02	1.673
S_o 962.11	1.0	3.50	2.969	+1.258	73.80	2228.07	24457.35	0	- 62.02	+ 798.08	2228.08	1.560
Constant Area Region	1.1	3.85	2.504	+ .8138	69.03	1946.20	24437.40					
	1.2	4.20	2.361	+ .5587	66.84	1771.77	24400.84					
	1.3	4.55	2.212	+ .3625	63.70	1659.08	24381.19					
	1.4	4.90	2.114	+ .2460	62.25	1586.62	24364.17					
	1.5	5.25	2.049	+ .1607	61.20	1537.66	24342.66					
	1.6	5.60	2.005	+ .1176	60.58	1504.02	24321.25					
	1.7	5.95	1.975	+ .0822	60.10	1482.13	24300.12					
	1.8	6.30	1.954	+ .0570	59.77	1466.75	24279.16					
	1.9	6.65	1.940	+ .0413	59.53	1456.10	24251.28					
	2.0	7.00	1.931	+ .0298	59.36	1448.11	24237.48					
	2.1	7.35	1.924	+ .0219	59.24	1443.30	24216.72					
	2.2	7.70	1.919	+ .0168	59.14	1440.44	24191.01					
	2.3	8.05	1.916	+ .0127	59.07	1438.08	24175.32					
	2.4	8.40	1.914	+ .0101	59.02	1436.19	24154.65					
	2.5	8.75	1.913	+ .0083	58.97	1435.35	24243.01					
	2.6	9.10	1.911	+ .0070	58.92	1434.78	24113.37					
	2.7	9.45	1.911	+ .0062	58.90	1433.30	24092.74					
	2.8	9.80	1.910	+ .0056	58.87	1433.53	24072.13					
	2.9	10.15	1.910	+ .0051	58.85	1433.26	24051.53					
	3.0	10.50	1.910	+ .0048	58.82	1433.00	24030.94					

$V_e(H_i) = \sqrt{\frac{W}{.001189\,\sigma_H (C_D S_o)_{max}}}$ = 58.638

A'

B' 3.100

C'

Note: Filling time calculated from Parachute Handbook[3] formula:

$t_f = \frac{.65 \lambda_g D_o}{V_i}$

$= \frac{.65 \times 22.8 \times 35}{145}$

$= 3.58$ sec.
(3.5 sec used)

V_{max}

$.00755\, D_o^3$

$\Sigma f(T,t_f)$

Δ

Program P7U

Subject: Opening of 35-ft Ring Sail Drogue Chute, Events 2a and 2b

LEGEND

D_o	parachute reference dia (ft)	Reg.00
C	coefficient of porosity	22.55
W	system weight (lb)	Reg.03
t_f	filling time (sec)	3.5 sec
$t_f/50$	interval time (sec)	Reg.02
t	actual time $T \cdot t_f$ (sec)	
H	parachute altitude (ft)	Reg.06
σ_H	density ratio, alt. H	Reg.08
$\sigma_{(H-1000')}$	density ratio, alt. (H-1000')	Reg.07
$\Delta\sigma/H$	density ratio difference / H	Reg.10
C_D	parachute drag coefficient	.78
S_o	" reference area, fully open	962.11
b	" " " fully closed	2.5
V_i	initial velocity (fps)	Reg.01
$(C_D S_o)_{max}$	parachute effective area (max)	Reg.10
$V_e(H_i)$	equilibrium velocity for initial altitude	

Registers	00	01	02	03	04	05	06	07	08	09	10	11	12	13
IN	D_o 35	V_i 145	$t_f/50$ .07	W 1430	.001189	T_i (0)	H_i 24874	$\sigma_{(H-1000)}$ .49017	σ_H .49008	0	$(C_D S_o)_{max}$ 750.46	—	b 2.5	50
OUT	q	V	"	"	"	T	$H_{1,2,3}$	D	·	ΣAH	$\Delta\sigma/H$	Area	Δv	ΔH

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Table A2. Event 3a. Deployment of Main Chute

Program P13A

Date: 6/17/76
Revised 7/28/76

	T	t(sec)	psf q	fps Δv	fps -v	lb D	ft H	lb W	fps V_e	ΣΔH
	0	0	1.910	-	-58.00	1433.53	24078.	667	-	0
	.02	.05	1.792	+1.636	-57.36	1344.83	24069.1		40.161	
	.04	.10	1.701	+1.4711	-55.90	1276.48	24066.3		40.159	
	.06	.15	1.621	+1.326	-54.466	1216.47	24063.5		40.157	
	.08	.20	1.551	+1.190	-53.267	1163.60	24060.82		40.155	
	.10	.25	1.488	+1.086	-52.182	1116.64	24058.18		40.153	
	.12	.30	1.433	+ .9856	-51.196	1075.31	24055.9		40.152	
	.14	.35	1.384	+ .8963	-50.30	1038.30	24053.1		40.150	
	.16	.40	1.339	+ .8164	-49.48	1005.21	24050.57		40.148	
	.18	.45	1.299	+ .7448	-48.738	975.94	24048.11		40.146	
longer intervals	.20	.50	1.264	+ .6804	-48.058	948.68	24045.60		40.145	- 26.31
	.30	.75	1.132	+ .4403	-45.42	849.43	24034.03		40.136	- 37.07
	.40	1.00	1.049	+ .2909	-43.607	787.88	24022.90		40.128	- 49.10
	.50	1.25	.99847	+ .1980	-42.547	747.80	24012.13		40.120	- 59.86
	.60	1.50	.9617	+ .1320	-41.771	721.70	24001.60		40.113	- 70.40
	.62	1.55	.9563	+ .1222	-41.649	717.64	23999.51		40.111	- 72.49
	.64	1.60	.9513	+ .1132	-41.536	713.90	23997.43		40.110	- 74.57
	.66	1.65	.9467	+ .1049	-41.430	710.45	23995.36		40.108	- 76.64
	.68	1.70	.9424	+ .0972	-41.333	707.26	23993.29		40.106	- 78.71
	.70	1.75	1.025	- .7437	-42.077	760.39	23991.20	1430	58.723	- 80.70
	.72	1.80	1.057	- .7166	-42.793	783.83	23989.08		58.721	- 82.92
	.74	1.85	1.089	- .6900	-43.483	817.17	23986.93		58.719	- 85.07
	.76	1.90	1.120	- .6640	-44.148	840.25	23984.74		58.717	- 87.26
	.78	1.95	1.1496	- .6386	-44.786	862.77	23982.51		58.714	- 89.49
	.80	2.00	1.1780	- .6130	-45.40	884.71	23980.23		58.712	- 91.74
	.82	2.05	1.207	- .5899	-45.99	906.06	23977.97		58.710	- 94.03
	.84	2.10	1.235	- .5665	-46.56	926.85	23975.66		58.707	- 96.34
	.86	2.15	1.262	- .5438	-47.10	947.02	23973.32		58.705	- 98.68
	.88	2.20	1.288	- .5217	-47.622	966.60	23970.95		58.702	-101.06
	.90	2.25	1.313	- .5004	-48.122	985.57	23968.55		58.700	-103.44

Registers	00	01	02	03	04	05	06	07	08	09	10	11	12	13
IN	-	$-v_i$ -58.0	$t_f/50$ .05	W_i 667	$\frac{\rho}{2}$ MSL .001189	T_i (0)	H_i 24078	$\sigma_{H+1000'}$ .42088	σ_H .40545	W_B/D	$(C_D S_o)_{max}$ 753.45	Count No. 50	0	$W_{OT}/\Delta H$
OUT	q	$-v_{1,2}$	-	W	-	T	$H_{1,2,3}$	D	-	$-\Sigma\Delta H$	-	-	$V_e/\Delta v$	$-\Delta H$

Note: This computation tracks the drogue chute from the moment of release of cryo unit to end of 0.5 second shock/deceleration period.

Subject: Event 3a
35': Drogue chute ring sail
64': Main chute fl.circ.

LEGEND

W_s	System Weight 1430
D_o	Chute nominal dia 35 ft
v_i	Initial (release) velocity
t_f	filling time 2.5
t	actual time (sec)
T	ratio t/t_f
W_i	Initial weight (chute + load)
W	Instantaneous weight
ρ	atm. density
H_i	release altitude
H	Instantaneous altitude
σ	density ratio ρ/ρ_o
W_B	Weight of ALBS balloon
W_{OT}	" other components suspended on drogue
C_D	coeff. drag (chute) .75
S_o	Ref. Area of chute (fully open)
$(C_D S_o)$	Effective drag area
V_e	Projected Equilibrium Velocity

Table A3. Event 3b Opening of Main Chute (Treated as combined chute)

Date: 7/28/76

Program P4U								Program P9	Program P10			
ft² AREA	(t/tf) sec T	sec t	psf q	fps Δv	fps -v	lb D	ft H	ft³ f(T, ti)	fps/sec dv/dt	lb F	lb Fo	Fo/Wg
[illegible],982.11	0	0	1.313	-	-47.62 (vi)	-	23771. (Hi)	0	+68.84	-873.5	556.49	.380
1283.80	.1	.35	1.370	-.1000	-40.60	1327.90	23783.8	9760.13	+20.61	-375.8	1084.24	.737
1605.30	.2	.70	1.341	+.2021	+40.06	1615.31	23736.5	22748.27	+ .06	+ .76	1420.2	.990
1927.20	.3	1.05	1.221	+.5205	+46.81	1760.15	23719.74	33415.64	-17.64	+223.81	1663.81	1.157
2248.90	.4	1.40	1.075	+.6037	+43.80	1812.97	23703.81	40014.08	-26.07	+330.86	1760.86	1.231
2570.60	.5	1.75	.9342	+.5848	-40.00	1800.99	23689.07	42390.38	-28.86	+366.24	1796.24	1.256
2892.20	.6	2.10	.8130	+.5257	+38.14	1763.53	23675.31	40567.60	-28.80	+368.41	1798.41	1.258
3213.90	.7	2.45	.7134	+.4565	+35.72	1719.62	23662.28	36213.77	-27.56	+349.75	1779.75	1.244
3535.60	.8	2.80	.6320	+.3013	-33.64	1678.23	23650.18	20566.72	-25.08	+320.67	1750.67	1.231
3857.30	.9	3.15	.5678	+.3381	+31.86	1642.57	23638.70	14779.57	+24.41	+300.70	1730.70	1.216
So 4179.00	1.0	3.50	.5146	+.2886	-30.32	1613.10	23627.82	0	-22.92	+290.80	1720.80	1.203
	1.1	3.85	.4836	+.1360	-29.50	1510.06	23617.30					
	1.2	4.20	.4603	+.0647	-28.95	1471.07	23607.10					
	1.3	4.55	.4626	+.0313	-28.75	1440.84	23597.10					
	1.4	4.90	.4504	+.0155	-28.65	1439.81	23587.07					
	1.5	5.25	.4578	+.0079	-28.58	1435.02	23577.05					
	1.6	5.60	.4571	+.0043	-28.56	1432.73	23567.05					
	1.7	5.95	.4568	+.0026	-28.53	1431.63	23557.07					
	1.8	6.30	.4566	+.0018	-28.52	1431.11	23547.01					
Constant Area Region	1.9	6.65										
	2.0	7.00										
	2.1											
	2.2											
	2.3											
	2.4											
	2.5											
	2.6											
	2.7											
	2.8											
	2.9											
	3.0											

$V_e(H_i) = \sqrt{\dfrac{W}{.001189\,\sigma_H (C_D S_o)_{max}}}$ = 28.49

A' 24.430
B' .07796
C' 20[illegible].64

V_{max}: 26218.75

$\dfrac{.00755\, D_o^2}{\Sigma f(T, t_i)}$

Δ^+ 26531.33
114.54

Program P7U

Subject: Event 3b opening of main chute. (Treated as combined chute) 55' ring sail (drogue) 64' [illegible] (main)

LEGEND

D_o	Parachute reference dia (ft)	Reg 00
C	Coefficient of Porosity	.048
W	System Weight (lb)	Reg. 03
t_f	filling time (sec)	3.5
$t_{f/50}$	interval time (sec)	Reg. 02
t	actual time $T \cdot t_f$ (sec)	
H	parachute altitude (ft)	Reg. 06
σ_H	density ratio, alt. H	Reg. 08
$\sigma_{(H-1000')}$	density ratio, alt (H-1000')	Reg. 07
$\Delta\sigma$/ft	density ratio difference/ft	Reg. 10
C_D	parachute drag coefficient	0.75
S_o	" reference area, fully open	
b	" " " fully closed	
$-v_i$	initial velocity (fps)	Reg. 01
$(C_D S_o)_{max}$	Parachute effective area (max)	Reg. 10
$V_e(H_i)$	Equilibrium Velocity for initial altitude	

Registers	00	01	02	03	04	05	06	07	08	09	10	11	12	13
IN	D_o 72.045	$-v_i$ -47.62	$t_{f/50}$ .07	W 1430	.001189	T_i (0)	H_i 23771	$\sigma_{(H-1000')}$ .68491	σ_H .16835	0	$(C_D S_o)$ [illegible]	--	b [illegible]	50
OUT	q	-v	"	"	"	T	$H_{1,2,3}$	D	--	$-\Sigma\Delta H$	$\Delta\sigma$/ft	Area	Δv	-ΔH

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Table A4. Event 4b. Drogue Chute Track

Program P13A — ALBS BALLOON EXTRACTION COMPUTATION

Date: 6/03/76

	T	t(sec)	psf q	fps Δv	fps $-v$	lb D	ft H	lb W	fps V_e	$\Sigma\Delta H$
	0	0	.4524	*	-28.370	310.600	23722.00	70.00	*	
	.02	.18	.2903	+11.4500	-16.924	217.870	23717.92	73.24	12.931	
	.04	.36	.1356	+1.9190	-15.000	151.800	23715.04	76.48	13.226	
	.06	.54	.1168	+.5773	-14.428	87.060	23712.40	79.72	13.515	
	.08	.72	.1125	+.1044	-14.323	84.540	23709.81	82.96	13.708	
	.10	.90	*	*	-14.414	*	*	86.20	14.075	
	.12	1.08	*	*	-14.580	*	*	89.44	14.346	
	.14	1.26	.11898	+.2135	-14.803	89.270	237[illegible].97	92.68	14.612	
	.16	1.44	*	+.2368	-15.033	*	*	95.92	14.874	
	.18	1.62	*	+.2262	-15.268	*	*	99.16	15.131	
	.20	1.80	.1309	+.2117	-15.505	98.216	23693.78	102.40	15.384	
	.30	2.70	.1519	+.2001	-16.659	113.900	2367[illegible].31	118.60	16.580	
	.40	3.60	.1731	+.1901	-17.743	129.870	236[illegible].82	134.80	17.711	
Longer intervals	.50	4.50	.1943	+.1815	-18.700	145.700	2364[illegible].37	151.00	18.764	
	.60	5.40	.2155	+.1730	-19.716	161.710	236[illegible].06	167.20	19.760	-91.94
	.70	6.30	.2367	+.1671	-20.661	177.660	23611.87	183.40	20.707	-110.12
	.80	7.20	.2580	+.1622	-21.345	193.610	235[illegible].88	199.60	21.610	-129.12
	.90	8.10	.2793	+.1611	-22.304	209.580	2357[illegible].11	215.80	22.476	-148.80
	.98	8.82	.2963	+.0812	-23.0[illegible]	222.360	23[illegible]	228.76	23.145	-165.25
	1.00	9.00	.3006	*	-23.211	225.5[illegible]	23[illegible].58	232.00	23.309	-169.47
	1.02	9.18								
	1.04	9.36								
	1.06	9.54								
	1.08	9.72								
	1.10	9.90								
	1.1[illegible]									
	1.14									

*NOT RECORDED

Drogue Chute Track

Subject: Event 4b
35' Drogue chute [illegible]
64' Main chute [illegible]

LEGEND

W_s	System Weight 1420
D_o	Chute nominal dia.
v_i	Initial (release) velocity
t_f	filling time 9.0
t	actual time (sec)
T	ratio t/t_f
W_i	Initial weight (chute + load)
W	Instantaneous weight
ρ	atm. density
H_i	release altitude
H	Instantaneous altitude
σ	density ratio ρ/ρ_o
W_B	Weight of ALBS balloon
W_{OT}	" other components suspended on drogue
C_D	coeff. drag (chute) .78
S_o	Ref. Area of chute (fully open)
V_e	Projected Equilibrium velocity for descending system of weight, W

Registers	00	01	02	03	04	05	06	07	08	09	10	11	12	13
IN	–	$-v_i$ 28.37	$t_f/50$ .18	W_i 70	$\frac{\rho}{2}$ MSL .00119	0	H_i 23722	$\sigma_{H-1000'}$ .485[illegible]	σ_H .46914	$W_B/0$ 180	$(C_D S_o)_{max}$ 250.45	Count No. 50	0	$W_{OT}/\Delta H$ 52
OUT	q	$-v_{1,2}$	–	W	–	T	$H_{1,2,3}$	D	–	$-\Sigma\Delta H$	–	–	$V_e/-v$	$-\Delta H$

Table A5. Event 4b. Main Chute Track

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Date: 6/03/75

ALBS BALLOON

Program P13A

EXTRACTION COMPUTATION

	T	t(sec)	psf q	fps Δv	fps -v	lb D	ft. H	lb W	fps V_e	ΣΔH
	0	0	.4824	*	+28.370	1091.12	23522.00	1360.00	*	
	.02	.18	.4809	+.7336	+29.106	1184.52	23518.82	1356.78	31.678	
	.04	.36	*	*	+29.671	*	*	1353.52	31.637	
	.06	.54	.5161	.4294	+30.100	1250.23	23506.16	1350.28	31.596	
	.08	.72	*	*	+30.423	*	*	1347.04	31.556	
	.10	.90	.5330	+.3307	-30.663	1288.24	23495.21	1343.80	31.515	
	.12	1.08	*	*	+30.838	*	*	1340.56	31.474	
	.14	1.26	*	*	+30.962	*	*	1337.32	31.433	
	.16	1.44	.5447	+.0860	+31.048	1314.28	23478.53	1334.08	31.392	
	.18	1.62	*	*	+31.105	*	*	1330.84	31.350	
longer intervals	.20	1.80	.5471	+.0312	-31.137	1319.00	23467.34	1327.60	31.309	
	.30	2.70	.5456	+.0322	-31.100	1316.43	23439.31	1311.40	31.102	
	.40	3.60	.5402	+.0366	-30.946	1303.42	23411.38	1295.20	30.895	
	.50	4.50	.5336	+.0407	-30.749	1287.07	23383.62	1279.00	30.687	
	.60	5.40	.5272	+.0418	+30.541	1271.91	23356.03	1262.80	30.478	-166.07
	.70	6.30	.5204	+.0422	-30.331	1256.08	23328.65	1246.60	30.267	-193.35
	.80	7.20	.5137	+.0425	-30.119	1240.42	23301.44	1230.40	30.056	-220.56
	.90	8.10	.5069	+.0427	-29.906	1225.14	23274.43	1214.20	29.844	-247.57
	.98	8.82	.5016	+.0429	-29.734	1210.12	23252.96	1201.24	29.674	-269.04
	1.00	9.00	.5002	+.0420	-29.692	1206.86	23247.61	1198.00	29.631	-274.39
	1.02	9.18								
	1.04	9.36								
	1.06	9.54								
	1.08	9.72								
	1.10	9.90								

*NOT RECORDED

Registers	00	01	02	03	04	05	06	07	08	09	10	11	12	13
IN	–	$-v_i$ 28.37	$t_f/50$ .18	W_i 1360	$\frac{\rho}{2}$ MSL 001189	T_i (0)	H_i 23522	$\sigma_H \cdot 1000$ 48011	σ_H .47243	$W_s/0$ 180	$(C_D S_0)_{max}$ 2413.74	Count No. 50	0 1430	$W_{OT}/\Delta H$ 52
OUT	q	$-v_{1,2}$	–	W	–	T	$H_{1,2,3}$	D	–	$-\Sigma\Delta H$	–	–	$V_e/-v$	$-\Delta H$

Main Chute Track

Subject: Event 4b
3a Drogue chute ring sail
4a Main chute ft. circ.

LEGEND

- W_s System Weight 1430
- D_0 Chute nominal dia.
- v_i initial (release) velocity
- t_f filling time 9.0
- t actual time (sec)
- T ratio t/t_f
- W_i initial weight (chute + load)
- W instantaneous weight
- ρ atm. density
- H_i release altitude
- H instantaneous altitude
- σ density ratio ρ/ρ_0
- W_B Weight of ALBS balloon
- W_{OT} " other components suspended on drogue
- C_D coeff. drag (chute) .75
- S_0 Ref. Area of chute (fully open)
- V_e Projected Equilibrium velocity for system of weight, W

Table A6. Event 4c. System Track Balloon Fully Extended

ALBS BALLOON

Program P13A EXTRACTION COMPUTATION

Date: June 4, 1976

T	t(sec)	psf q	fps Δv	fps -V	lb D	ft H	lb W	fps V_e	ΣΔH
0	0	.5002	-	+28.602	-	23248.	1430		
.02	.18	.4826	+.3006	+28.301	1526.53	23242.69		28.234	
.04	.36	.4744	+.2888	+28.016	1500.48	23239.44		28.231	
.06	.54	.4684	+.2007	+28.806	1481.74	23233.23		28.228	
.08	.72	.4641	+.1544	+28.652	1468.10	23227.07		28.226	
.10	.90	.4610	+.1141	+28.538	1458.14	23221.92		28.224	
.12	1.08	.4586	+.0848	+28.453	1450.85	23216.79		28.221	
.14	1.26	.4570	+.0628	+28.300	1445.50	23211.67		28.219	
.16	1.44	.4557	+.0469	+28.343	1441.57	23206.57		28.216	
.18	1.62	.4548	+.0352	+28.308	1438.66	23201.47		28.214	
.20	1.80	.4541	+.0260	+28.282	1436.55	23121.38		28.211	
.22	1.98	.4537	+.0202	-28.261	1434.88	[illegible]		28.208	
.24	2.16	.4533	+.0156	-28.246	1433.84	2 [illegible].20		28.206	
.26	2.34	.4530	+.0121	-28.234	1432.09	2 [illegible]1.12		28.203	
.28	2.52	.4528	+.0090	+28.224	1432.37	2 [illegible]76.03		28.201	
.30	2.70	.4527	+.0077	+28.216	1431.91	2 [illegible].05		28.198	
.32	2.88	.4526	+.0064	+28.210	1431.67	2 [illegible].88		28.196	
.34	3.06	.4525	+.0053	+28.204	1431.32	2 [illegible].80		28.193	

System Track

Balloon Fully Extended

Subject: Event 4c Drogue chute (r. [illegible]) / Main chute ([illegible])

LEGEND

- W_s System Weight 1430
- D_0 Chute nominal dia.
- v_i initial (release) velocity
- t_f filling time N/A
- t actual time (sec)
- T ratio t/t_f
- W_i Initial weight (chute + load)
- W Instantaneous weight
- ρ atm. density
- H_i release altitude
- H instantaneous altitude
- σ density ratio ρ/ρ_0
- W_B Weight of ALBS balloon
- W_{OT} " other components suspended on drogue
- C_D coeff. drag (chute) [illegible]
- S_0 Ref. Area of chute (fully open)
- V_e Projected Equilibrium velocity for system of weight, W

Registers	00	01	02	03	04	05	06	07	08	09	10	11	12	13
IN	-	$-v_i$ -28.602	$t_f/50$ .18	W_i 1430	ρ_s MSL .001189	T_i (0)	H_i 23248.	$\sigma_{H-1000'}$ .49375	σ_H .47696	W_B/O	$(C_D S_0)_{max}$ 3165.19	Count No. 50	0	$W_{OT}/\Delta H$
OUT	q	$+v_{1,2}$	-	W	-	T	$H_{1,2,3}$	D	-	$+\Sigma\Delta H$	-	-	$V_e/+v$	$+\Delta H$

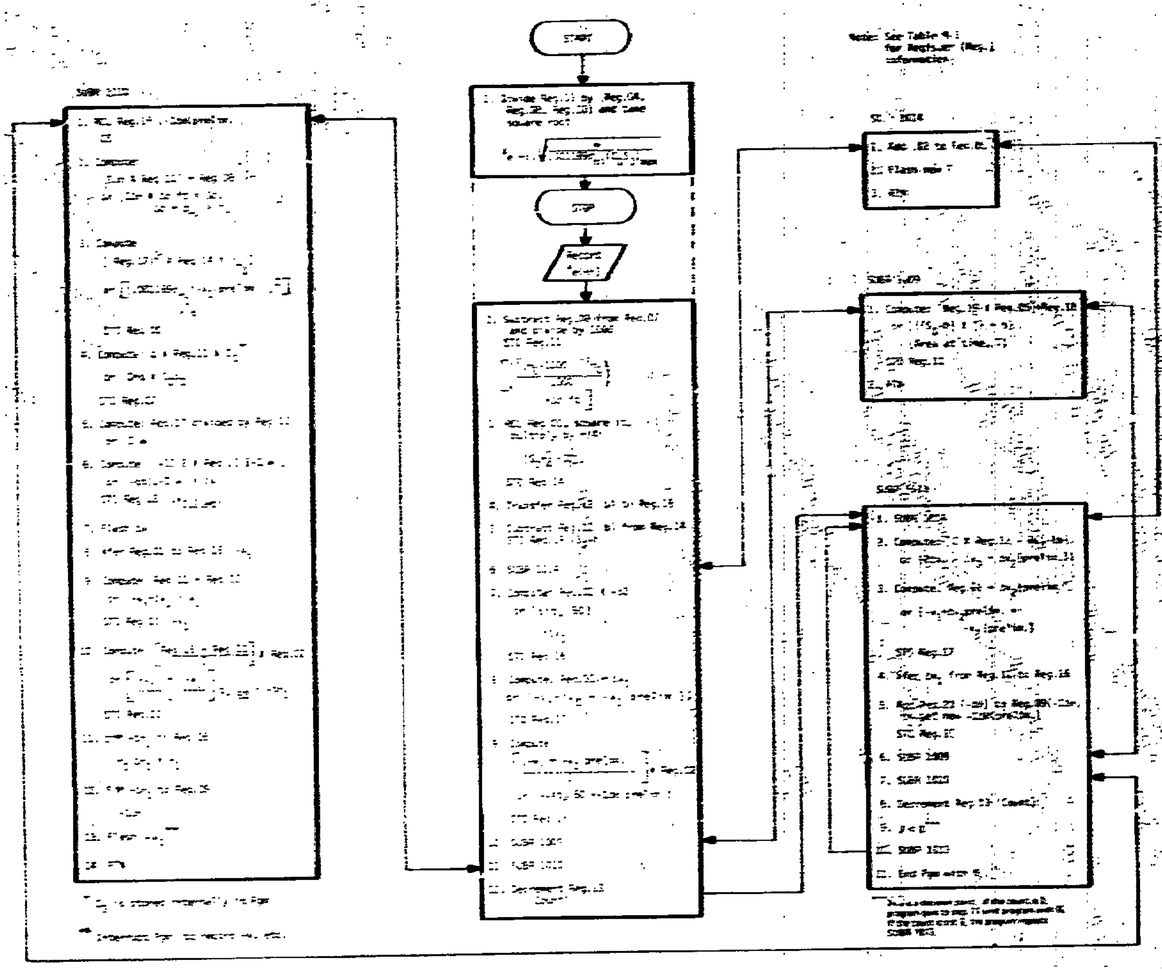


Figure A1. Flow Diagram for Program P4U: Opening Parachute Descent Parameters

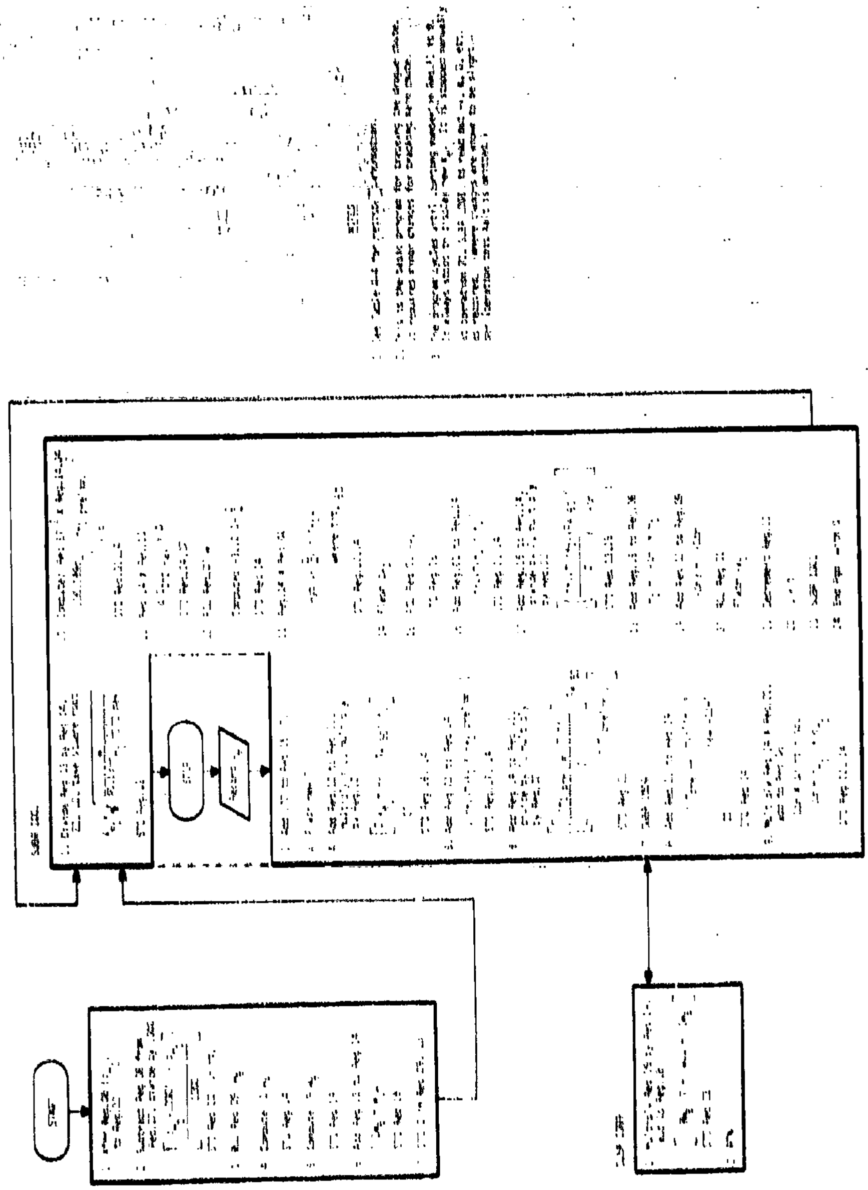
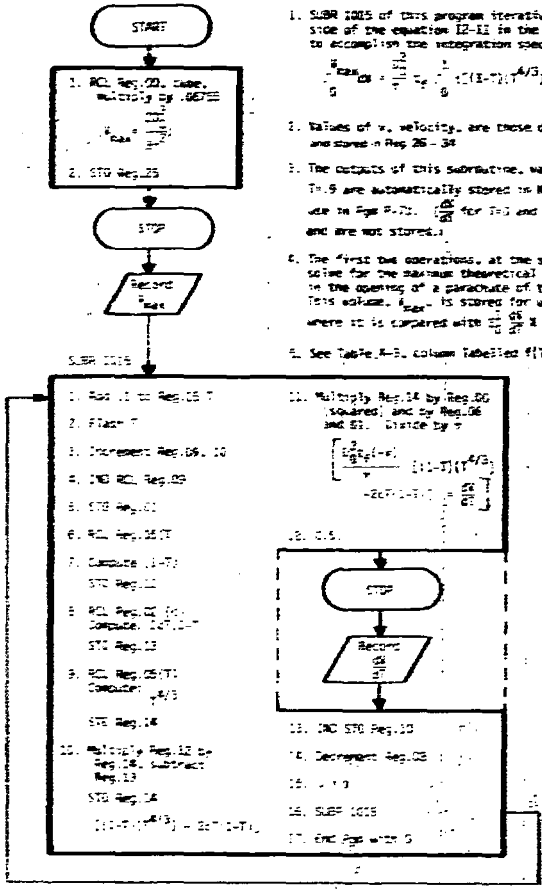


Figure 12. Flow Diagram for Program P-13A: ALBS Balloon Extraction Process

Registers	
00	C_D drag manual input (m.i.)
01	[illegible] entered by pgm
02	[illegible] porosity coeff., (m.i.)
03	
04	
05	[illegible]
06	t_f [illegible]
07	
08	counting no. for cycles [illegible]
09	counting no. for indirect storage [illegible]
10	counting no. for indirect address [illegible]
11	
12	[illegible]
13	[illegible]
14	
15	
16	[illegible] for T=.1
17	T=.2
18	T=.3
19	T=.4
20	T=.5
21	T=.6
22	T=.7
23	T=.8
24	[illegible] for T=.9
25	$\dot{s}_{max}$ [illegible]
26	[illegible] for T=.1
27	[illegible] for T=.2
28	[illegible]
29	
30	(from Pgm P8)
31	(manual input)
32	
33	
34	[illegible] for T=1.0



NOTES

1. SUBR 1015 of this program iteratively solves the right hand side of the equation 12-11 in the Parachute Handbook (ref. 13) to accomplish the integration specified on the left side.

$$\int_0^{\dot{s}_{max}} ds = \frac{\pi D_0^2}{4}\, t_f \int_0^1 \{[(1-T)T^{4/3}]-2c\bar{T}(1-T)\}v\, dT$$

2. Values of v, velocity, are those developed by Program P8 and stored in Reg 26 – 34.

3. The outputs of this subroutine, values of $\frac{ds}{dT}$ for T=.1 to T=.9 are automatically stored in Reg.16 thru 24 for later use in Pgm P-7. ($\frac{ds}{dT}$ for T=0 and T=1 are 0 in every case and are not stored.)

4. The first two operations, at the start of the program, solve for the maximum theoretical volume to be developed in the opening of a parachute of the specified diameter. This volume, $\dot{s}_{max}$, is stored for use in Program P-7 where it is compared with $\frac{ds}{dT}$ x T.

5. See Table A-3, column labelled f(T,t_f) for typical outputs of this subroutine.

Figure A3. Flow Diagram for Program P-9: Aid to Determining Parachute Opening Time

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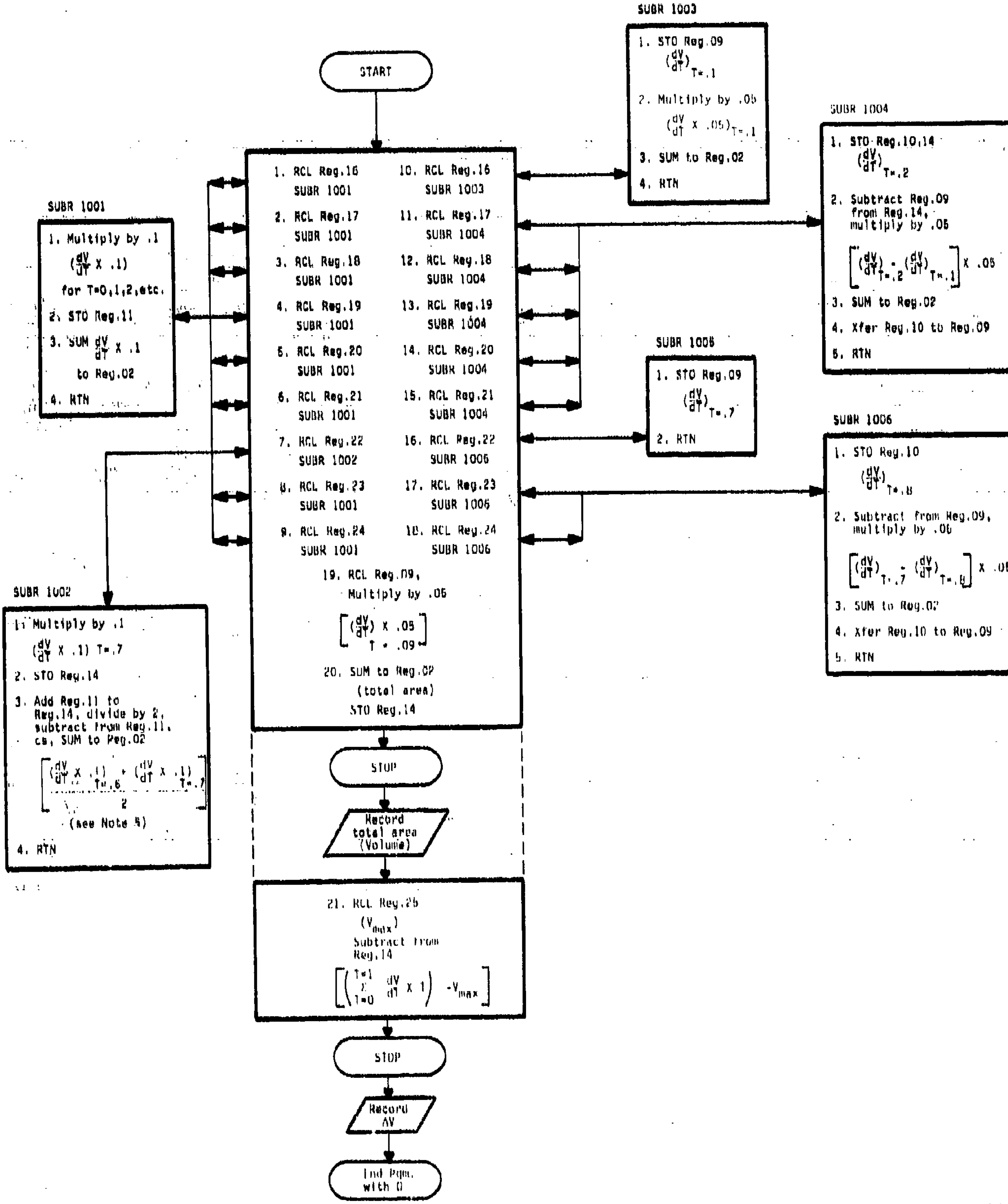


Figure A4. Flow Diagra

SUBR 1003

1. STO Reg.09 $\left(\frac{dV}{dT}\right)_{T=.1}$
2. Multiply by .05 $\left(\frac{dV}{dT} \times .05\right)_{T=.1}$
3. SUM to Reg.02
4. RTN

SUBR 1004

1. STO Reg.10,14 $\left(\frac{dV}{dT}\right)_{T=.2}$
2. Subtract Reg.09 from Reg.14, multiply by .05 $\left[\left(\frac{dV}{dT}\right)_{T=.2} - \left(\frac{dV}{dT}\right)_{T=.1}\right] \times .05$
3. SUM to Reg.02
4. Xfer Reg.10 to Reg.09
5. RTN

SUBR 1005

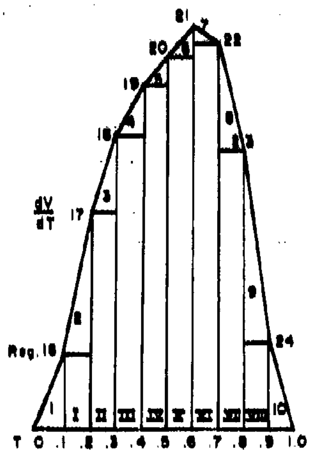
1. STO Reg.09 $\left(\frac{dV}{dT}\right)_{T=.7}$
2. RTN

SUBR 1006

1. STO Reg.10 $\left(\frac{dV}{dT}\right)_{T=.8}$
2. Subtract from Reg.09, multiply by .05 $\left[\left(\frac{dV}{dT}\right)_{T=.7} - \left(\frac{dV}{dT}\right)_{T=.8}\right] \times .05$
3. SUM to Reg.02
4. Xfer Reg.10 to Reg.09
5. RTN

NOTES

1. If the values of $\frac{dV}{dT}$ from Program P-9 (stored in Reg.16-24) are plotted against T, a curve similar to the one below will be obtained. Program P-7U measures the area under this curve by adding the areas of the 8 rectangles and 10 triangles into which it can be divided. For example, the area of rectangle 1 is b X h or 0.1 X the value of $\frac{dV}{dT}$ for $T=.1$, which is stored in Reg.16. The area of triangle 1 is 1/2 bh or 0.05 X $\frac{dV}{dT}$ for $T=.1$. As each segment area is calculated it is "summed" to Reg.02, so that at the end of the program the contents of Reg.02 equal $\Sigma_0^1 \frac{dV}{dT} \times T$. This sum is then compared against V_{max} computed by Program P-9 and stored in Reg.25. If the discrepancy is large, P-9 must be rerun, using values of -v (velocity) obtained by a rerun of P4U with a new value of t_f. If $\Sigma \frac{dV}{dT} \times T$ approximates V_{max}, Program P-10 is then run.



PLOT OF $\frac{dV}{dT}$ vs T

2. Although the curve shown above is typical, the actual configurations vary from case to case. The apex (highest point) may occur anywhere from T=.3 (Reg.18) to T=.7. This program was set up as a "universal" program, to cover all cases, with a minimum of change. (Hence, the U in the program number.) If the apex is at T=.3, the successive values of $\frac{dV}{dT}$ descend from T=.4 to T=1.0. If the apex is at T=.7, the descending values occur only from T=.8 to T=1.0. This is important in the computation of the triangle areas. SUBR 1004 covers ascending values, in which case the previous $\frac{dV}{dT}$ is subtracted from the new $\frac{dV}{dT}$ to obtain the value of h for the 1/2 bh computation. SUBR 1006 covers descending values of $\frac{dV}{dT}$, in which case the following value is subtracted from the new value. The plan here is to select the appropriate subroutine at each step of the process of calculating triangular areas.

3. In actual practice it has been found that the program as shown is adequate and that there is no real need to juggle subroutines to accommodate the shifting apex.

4. The triangle which occurs just to the right of the apex (triangle 7 in the curve above) is not separately computed. Its area is included in the computation of the tallest rectangle. (see note 5)

5. Subroutine 1002 determines the area of the tallest rectangle, using a somewhat complicated method aimed at accommodating the shifting apex described in Note 2. It computes a rectangular area based on the height value of the apex and stores this area in Reg.11 as well as summing it in Reg.02. It then computes a 2nd area based on the height value of the next point on the curve. Only one area is needed, however, per the geometrical constraints of the figure. The area just computed is added to the area stored in Reg.11 and divided by two. This average area is the one which will be used. Since the Reg.11 area has already been summed to Reg.02 an adjustment is accomplished by subtracting the difference between the Reg.11 area and the new average area from Reg.02. In examining the curve above it will be seen that this computation also includes the area of triangle 7.

Figure A4. Flow Diagram for Program P7U: Computation of Area Under Curve

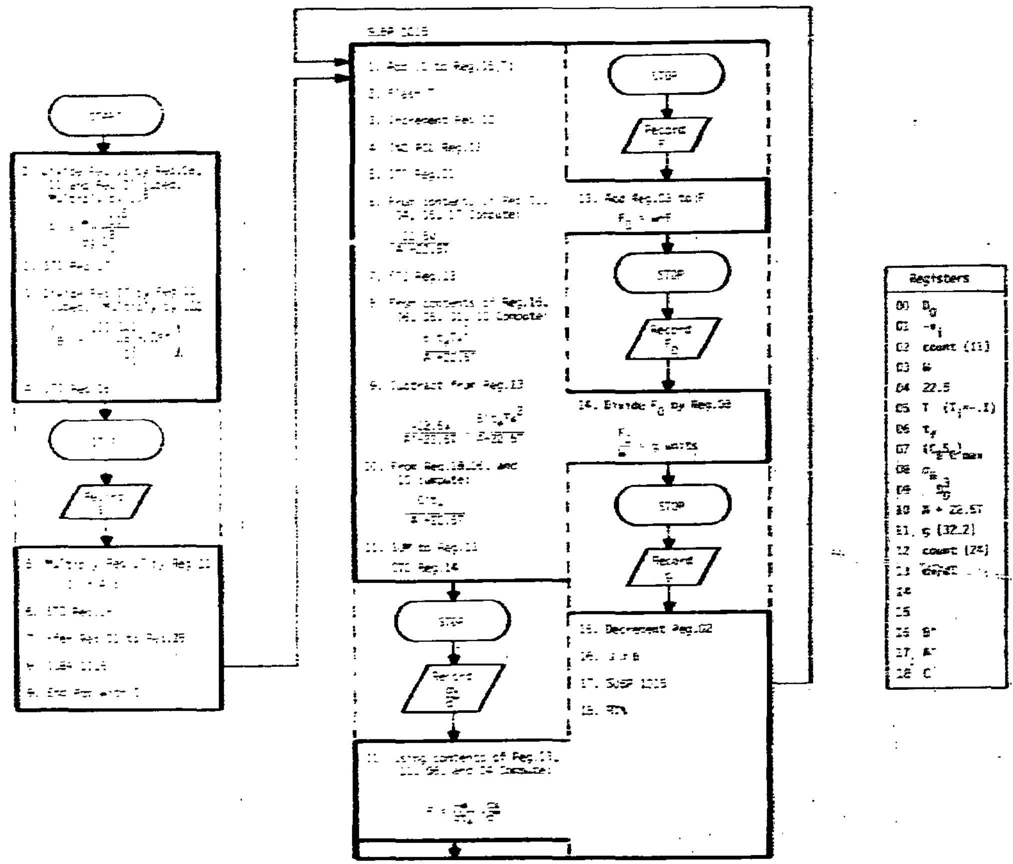


Figure 15. Flow Diagram for Program P-10: Solution of Opening Shock Force

Appendix B

ALBS Special Balloon

BALLOON SPECIFICATION SHEET
SPECIFICATION NO. 760421.01
AFGL MODEL NO. TTV-007
(POLYETHYLENE)

1. PERFORMANCE

   Minimum Payload: 300 Pounds Floats at 75,000 ft
   Payload: 504 Pounds Floats at 70,200 ft
   Based on a Nominal Balloon Weight 177 lbs

2. DESIGN AND DIMENSIONS

   Theoretical Maximum Volume .157 Million ft^3
   Gore Length 101.7 ft. Maximum Diameter 72.58 ft
   Minimum Inflated Height 61.53 ft. Number of Gores 28.
   Gore Half Width, Base: 23.4 in., Apex: 35.3 in.
   Gore Pattern: Tailored with Rectangular End Sections
   Rated Load Tape Strength: N/A lbs
   Number of Ducts 4 Area (Each Duct): 1.00 ft^2
   Ducts Located on Gores 1, 8, 15, and 22
   Base Mark Line to Elliptical Opening 32.8 ft
   Base Mark Line to Detachment Point 5 ft
   Length of Detached Duct 5 ft

Inflation Tubes: 1 each, 107.7 ft long located on Gore 1 at a distance 1 ft from Apex Mark Line. Tube to be internal to the balloon.

Destruct Device Located on Gores No. 13 and 27. Refer to Section 4.

3. MATERIALS

GORES: 1.5 MILS THICK, PER SPECIFICATION MIL-P-4640 (USAF).

DUCTS: 1.5 MILS THICK, PER SPECIFICATION MIL-P-4640 (USAF).

CABLE SHEATH: 2.0 MILS THICK, PER SPECIFICATION MIL-P-4640 (USAF).

INFLATION TUBE(S): 3 MILS THICK, 0.4 in. FLAT WIDTH, MADE FROM SAME GRADE RESIN AS USED FOR BALLOON GORES.

REINFORCED ADHESIVE TAPE: 3M COMPANY 890 TAPE.

UNREINFORCED ADHESIVE TAPE: 3M COMPANY Y8307 TAPE OR W.R.G. SSA-10-TAPE.

4. APPLICABLE DRAWINGS

APEX END FITTING TYPE PER DRAWING: B10102 and B10104

BASE END FITTING TYPE PER DRAWING: B10102 and B10104

VALVE COVER PLATE ASSEMBLY PER DRAWING: B-10103

VALVE CABLE PER DRAWINGS: B10101-01 and B10107

DESTRUCT DEVICE PER DRAWING: SK72075.01

5. APPLICABLE SPECIFICATIONS

TITLE OR SUBJECT	NUMBER OR SOURCE
"GENERAL ENGINEERING SPECIFICATIONS FOR BALLOONS FABRICATED FROM HEATSEALABLE PLASTIC FILMS" OCTOBER 1973	LCB-01
"BALLOON PACKAGING AND BOXING" OCTOBER 1973	LCB-02
"PRODUCTION TENSILE TEST METHODS FOR FIN TYPE BALLOON GORE HEAT SEALS" JULY 1974	LCG-03
TENSILE TESTING OF BALLOON LOAD TAPES	CONTRACTOR
QUALITY CONTROL	MIL-Q-9858A

6. RECORDS

(1 Set to Contracting Officer, 1 Set to be Packed in Balloon Box)

"Balloon Production Record Summary" dated October 1973

"Balloon Specification Sheet"

"Payload Altitude Curve"

7. MISCELLANEOUS

Dimensions of duct ellipse axes shall be as determined by local gore width and manufacturing considerations, but minor (horizontal) axis shall not be more than one half the major axis.

Apex fitting shall accommodate 1 each EV-13 valve.

Destruct device buttons shall be fabricated from aluminum. Destruct device screw shall be made from metal compatible with the button material over the complete range of operating temperatures. The screw strength shall be consistent with the destruct line strength.

Balloon folding shall be in accordance with Figure 2, LCG-02 unless specific exception is requested and approved.

Prior to sealing balloon in the red polyethylene wrapper, balloon shall be checked for twists. Twists, if found, shall be removed using sound handling practices.

Balloon shall be sealed within reefing sleeve. Reefing sleeve shall begin 15 ft from apex. Reefing sleeve shall be 3 mils thick, one side red and one side clear. Tear panel shall be 1 mil thick.

Addendum

Between the time of submission of the first draft of this report for publication and the receipt of manuscript for review by the author, two major engineering changes have been made in the ALBS test system configuration. It is suggested that the reader approach the report in its first form, and then proceed to incorporate the changes. In this way, the revisions should become more meaningful and more readily visualized.

The first change involves the distribution of weight on the main canopy. In the new configuration only the balloon and its protective soft pack will be mounted at the main canopy apex. The other components (communications relay, ballast, command/control instrumentation) will be positioned below the main canopy just above the cryogenics unit. (The reader is asked to examine Figure 7b, and mentally to rearrange components as suggested above. A soft pack should be substituted for the aluminum framework.)

This weight redistribution provides a more favorable ratio of apex weight vs bottom weight and eliminates the need for ballast mentioned in the main text. To accomplish this weight change, the method of recovering the cryogenic unit had to be revised. The cryogenic unit will now fall away from the payload at the base of the main chute and will descend on its own parachute, which will have been packed until this point. The main chute will collapse when the balloon starts its ascent and it will be carried to balloon float altitude with the payload suspended beneath it. Later on, it will serve as the recovery chute for the payload when the balloon flight is terminated. (The reader is asked to compare the description above with the concepts depicted on Figures 12 and 13 and to make the necessary visualization changes.)

The second change is in the choice of parachutes. The drogue chosen for the initial El Centro tests will be a 32-ft diameter ring slot chute. The main chute will be a 42-ft diameter ring sail chute. It is believed that the more favorable dynamic pressures obtainable with this chute combination will enhance system performance. (Other parachute arrays, including a cluster, are under consideration as back-up systems in the event that the preferred array is shown to be unsuitable.)

As a result of the above changes, the numerical values listed in Table 2 and the supporting tables are obsolete in part. New values have been computed using the same basic procedures, and they will assist in test planning. (They will not be given here.)

Because of the changes and because of administrative delays in effecting a working agreement between the Air Force Flight Test Center and the Air Force Geophysics Laboratory, the flight test program at El Centro has been delayed by two months and will now commence in January 1977.

As a matter of interest, the program used to generate the values listed in Table 5 has been improved in several respects. (The original version of this program, P-14B, is outlined in Figure 11.) It has been translated into FORTRAN by Mr. Robert Vesprini of Emmanuel College and is now a valuable tool for quickly gauging the effect of changes in gas temperature and other parameters. In addition, the L/M ratio computation has been included in the program and is performed for each iteration.